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ADVANCED MANNED LAUNCH SYSTEM (AMLS) STUDY FINAL REPORT - TASK 3

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FOREWORD

Manned Launch System (AMLS) Study, have been published to satisfy the DRDs. The principle objective of the Task Assignment was to conduct a detailed analysis to determine whether a fully-reusable two-stage manned launch system concept can really achieve simpler operations with lower cost per flight at a low life cycle cost (LCC). This vehicle system was designed for crew safety, simple operations, and high operational utilization. The results of the AMLS reference system concept development are documented in the following Rockwell Space Systems Division reports:

SSD91D0269	Study Groundrules (DRD 2)
SSD91D0674	Final Report (DRD 12)
SSD91D0675	Hardware/Software Design Description (DRD 3)
SSD91D0676	Acquisition Phase Definition (DRD 4)
SSD91D0677	Operations and Support Analysis (DRD 5)
SSD91D0678	Life Cycle Cost Analysis (DRD 7)
SSD91D0679	Technology Development Plan (DRD 8)
SSD91D0271-1	Subsystem Design and Analysis (DRD 10)
SSD91D0271-2	Operations and Support Analysis (DRD 10)
SSD91D0271-3	Technology/Acquisition/LCC (DRD 10)

ACKNOWLEDGMENTS

The performance of this study would not have been possible without the contributions of a highly experienced and dedicated contract team and additional support from many other organizations and functional areas, both government and industry. These contributions have focused a wealth of knowledge and talents to the definition of a next generation cost-effective manned spacecraft system.

We and our counterparts at NASA/Langley have established a far closer relationship than the normal contractor/customer relationship. Our people have been working together on almost a daily basis with each group providing direct support to the study. Special acknowledgments are given to:

Howard Stone	Technical Monitor
Doug Stanley	Performance and Systems Design
Jim Robinson	Structural Analysis
Doug Morris	Operations
Arlene Moore	Life Cycle Costing

The study team that contributed to the depth and breadth of this study is composed of a number of Rockwell organizations supported by highly respected subcontractors. The Rockwell Space Systems Division (SSD) in Downey was the lead organization for the study and provided the major engineering, manufacturing, and operations support for the study. Rockwell's KSC function provided launch site operations support while our Space Operations Center provided mission planning and flight support. Johnson Controls (formerly Pan Am World Services) provided critical support in two major areas: airline operations concepts and KSC ground operations. The key personnel contributing to the study included:

Rockwell:

Carl Ehrlich	Program Manager
Jack Potts	Deputy PM and Systems Engineering
Jerry Brown	Subsystem Design
Ken Schell	Manufacturing and Verification
Mary Manley	Ground Operations and Support
Irving Chen	Technology Assessment
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Chuck Urrutia	Launch Site Operations
Ray Randolph	Mission Operations

Johnson Controls:

Jim Morris	Airline/Aircraft Operations
Will Linger	Ground Operations at KSC

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ACRONYMS

A&P	Airframe and Powerplant
ACRV	Assured Crew Return Vehicle (ACRV)
AMLS	Advanced Manned Launch System
ATA	Air Transport Association
CAP	Crew Activity Planning
CNDB	Civil Needs Data Base
COTS	Commercial-Off-The-Shelf
DRM	Design Reference Mission
EVA	Extra Vehicular Activity
FPOT	Flight Power Operating Times
GPOT	Ground Power Operating Times
GSE	Ground Support Equipment (GSE)
HC	Head Count
HPF	Horizontal Processing Facility
IOC	Initial Operations Capability
KSC	Kennedy Space Center
LaRC	Langley Research Center
L/MCC	Launch/Mission Control Center
LRU	Line Replaceable Unit
MA/FH	Unscheduled Maintenance Actions/Flying Hour
MCSP	Mission Completion Success Probability
MECO	Main Engine Cut Off
MTBCF	Mean-Time-Before-Critical-Failure
MTBF	Mean-Time-Between-Failure
MTBM	Mean-Time-Between Unscheduled Maintenance
MTBR	Mean-Time-Between-Removal
MTTR	Mean-Time-To-Repair
OFT	Orbital Flight Test
PCS	Payload Containment System
PCSPF	Payload Containment System Processing Facility
PCSPF	Payload Containment System Processing Facility
POCC	Payload Operations Control Center
PLS	Personnel Launch System
R/M	Reliability and Maintainability
SLF	Shuttle Landing Facility
SLOC	Software Lines of Code
SSCC	Space Station Control Center
SSF	Space Station Freedom
TPS	Thermal Protection System
UMA	Unscheduled Maintenance Actions
UMMH	Unscheduled Manhours

1.0 INTRODUCTION AND SUMMARY

The Space Shuttle was originally envisioned as a means of routine manned access to low earth orbit at a relatively low cost. As the Shuttle program progressed, budgetary pressures forced design compromises. Besides designing the system for payload delivery performance, these compromises precluded the full realization of the original cost goals. However, to continue to be the world's leader in space exploration and operations, space transportation must become a relatively small and stable part of the NASA budget. This would free funding for major new programs such as lunar and Mars exploration and utilization.

In recent years, NASA and the Air Force have emphasized that low delivery costs are necessary to accommodate the required national launch objectives of the future. Several NASA studies, the joint NASA/DOD Space Transportation Architecture Studies (STAS), and the Advanced Launch System (ALS) studies, showed the need for a multi-vehicle space transportation system with designs driven by operational criteria. In addition, technology advances were identified that are expected to make new system designs more operationally efficient than current launch systems.

Two classes of vehicles, with some possible common elements, are emerging as the leading candidates for the space transportation system fleet. One class is the unmanned booster designed to carry over 50,000 pounds of bulk cargo, propellants, and large satellites to orbit at a lower cost per pound than present launch systems. The second class consists of smaller manned vehicles that carry personnel and/or priority cargo to and from orbit, or perform on-orbit servicing and repair missions. These payloads could range up to the weight and size of the Space Station logistics module while the passenger carrying capabilities could be on the order of 4 to 10, depending on the mission requirements.

The AMLS, for the purposes of this study, is visualized in Figure 1-1 as an eventual replacement for the Space Shuttle system. It will provide the same services as the Space Shuttle system but avoids the problems of the Shuttle by incorporating lessons learned by capitalizing on an extensive empirical database. After a phasing in period, it will provide much of the up-cargo and personnel transportation during its period of operation, complemented by the PLS and NLS. Other alternatives exist or may exist to provide future transportation, but they are not a consideration for this study.

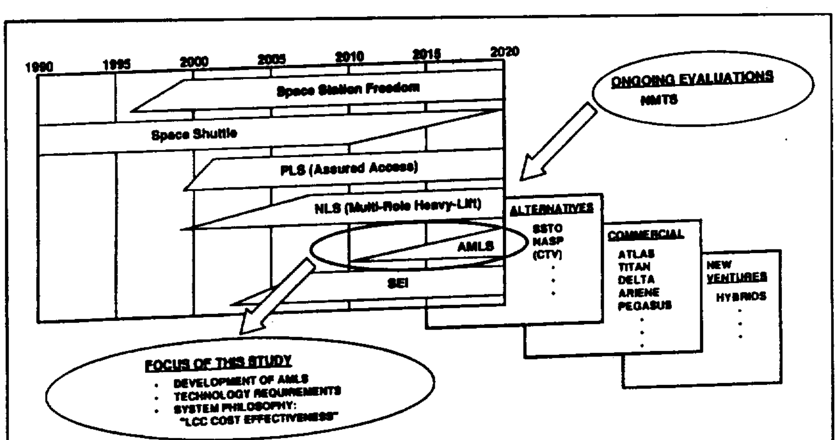

Figure 1-1. AMLS is a Key Option for Future Space Transportation Systems.

The principal objective of the Advanced Manned Launch System program, therefore, is to provide a detailed analysis of these sortie-class vehicles to determine whether NASA-developed concepts can really achieve simpler operations with lower cost per flight at an affordable life cycle cost. Subordinate objectives include determining the ability to design the system (vehicles, acquisition, and operations) for low cost operations while integrating the interactive effect on the design, development, test, validation, and production costs.

This study translates these objectives, characteristics, and new recommendations advanced by the study team into specific system design attributes and an identification of the cost savings that might be realized if they were to be implemented.

The current Task Assignment focuses on the in-depth development and assessment of a two-stage fully reusable launch vehicle with its supporting facilities and operating system (Figure 1-2). The AMLS vehicle concept was provided by the NASA Langley Research Center (LaRC). Like the prior study of the HL-20 lifting body Personnel Launch System (PLS) concept, the system will utilize cost-effective, state-of-the-art technologies existing at the initiation of the DDT&E phase (Phase C): FY 2000 in the case of the AMLS. It is expected to reach operational status in 2010 and will have a nominal operating life time of thirty years.

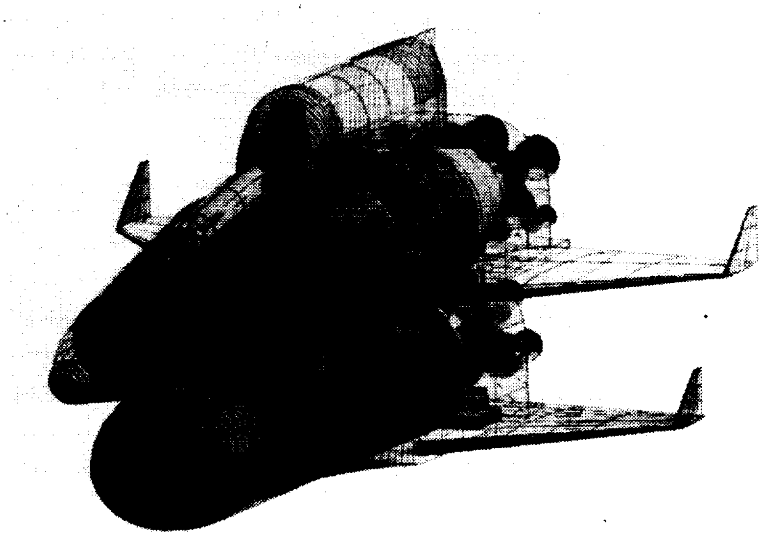
Figure 1-2. Two-Stage Fully-Reusable Launch System.

The objectives of the AMLS Task Assignment are to design and quantify launch vehicle systems and subsystems; to establish requirements for their reliability and maintainability; to define operational approaches, and manufacturing and operational facilities; and to develop a database for life cycle costing. Technology availability has been assessed and development program plans and schedules for the critical technologies will be developed.

This report documents the major activities leading from the design requirements established by the operations and manufacturing functional areas that have led up to the definition of the reference system design concept.

In this report, this unique approach to cost efficient operations of a large payload-carrying reusable manned launch system. The report has been structured to cover each major functional area separately. There is no "best" sequence for discussion, since each of the major functional areas contributed equally and concurrently to the definition of the reference system, but the requirements of the operations and manufacturing functions strongly influenced the ultimate design of the system. The flight system design is presented first in order to provide an enhanced understanding of what is being manufactured, validated, operated, and maintained. The groundrules and system requirements were, of necessity, defined early on to guide the initial development.

The study team for this Task Assignment is composed of the same Rockwell organizations and most of the same personnel as participated in the earlier PLS Task Assignments. The Rockwell Space Systems Division (SSD) in Downey is the lead organization for the study and provides the major engineering, manufacturing, and operations support for the study. Rockwell's KSC function provides launch site operations support while our Space Operations Center provides mission planning and flight support. Johnson Controls (formerly Pan Am World Services) provides critical support in two major areas: airline operations concepts and KSC ground operations. The results of the team's combined efforts are presented here and in a series of companion documents, References 1-1 to 1-6.

The basis for this approach to the AMLS study has been the same as for the earlier PLS system design activities: cross-functional team emphasis on those features enhancing the operation of the system as well as the fabrication of the system leading to lower life cycle costs. These features have been incorporated into the design of the flight vehicles as well as into the design of the operating system.

The following material presents an overview of the current definition of the reference system as we have developed it from the baseline concept given to us at the outset of this Task Assignment. We have incorporated several changes that we feel will enhance the capability of the system to meet low LCC goals.

1.1 GROUNDRULES

The definition of the AMLS groundrules was completed during the initial phase of the effort. These groundrules reflect the requirements of AMLS DRM-1 and have been developed from NASA-provided groundrule documents and from a review of applicable study report documents. The reference mission (DRM-1) has the following principal characteristics:

- Space Station Freedom cargo transport and crew rotation
- Destination: 220 nmi at 28 deg inclination
- 10 personnel (2 flight crew + 8 passengers)
- 40,000 pounds cargo and logistics up & down
- 15-ft diameter x 30-ft long payload bay
- 72-hour mission duration
- KSC is the primary launch & landing site
- Design shall not preclude other possible missions

Table 1-1. Principal Groundrules.

• PROVIDES TRANSPORT TO SPACE STATION (DRM 1)
• 2 CREW, 8 PASSENGERS, AND
• 40,000 POUNDS PAYLOAD
• DRM 1 DOES NOT PRECLUDE OTHER MISSIONS
• BERTH AT STATION SHUTTLE NODE
• MODULARIZED PAYLOAD CONTAINMENT SYSTEM (PCS)
• BOTH STAGES FULLY REUSABLE
• LAND HORIZONTALLY AT KSC
• IOC 2010 - 2020
• TECHNOLOGY LEVEL 6 IN 2000
• ENHANCED LAUNCH PROBABILITY
• DEMONSTRATE OPERATIONAL EFFICIENCY, MAINTAINABILITY, AND REPAIRABILITY

The principal groundrules used to conduct the study are presented in Table 1-1. They have been periodically updated during the course of the study. The full set consists of:

- General groundrules - used to perform both the overall study tasks and documentation requirements
- Mission design groundrules -- used for mission planning
- Subsystem design groundrules -- used for the AMLS system design
- Operations and support groundrules -- used for ground operations
- Payload containment system groundrules -- used to establish the approach to processing payloads

1.2 PROGRAM REQUIREMENTS DRIVE SYSTEM DESIGN

The basic program has the principal objectives of achieving high levels of operational efficiency at affordable life cycle costs while maintaining high operational utilization and crew safety. These goals, summarized in Table 1-2, have driven the design of the Rockwell AMLS concept from the outset. The system design reflects the operational goals through design features that have been incorporated into the flight vehicle design concept. It also provides features that facilitate manufacturing, operations, maintenance, and inspection and overhaul.

The system concept developed for the AMLS reflects an integrated approach to the design of the system. No single area (subsystems, design layout, manufacturing, nor operations) dominated the design but rather all program requirements were addressed concurrently in initiating the design activity.

Table 1-2. Program Requirements and Features.

PROGRAM REQUIREMENT	AMLS FEATURES
CREW SAFETY	PD ESCAPE SYSTEM CREW MODULE INTEGRITY (WATER LANDING) MULTIPLE INGRESS/EGRESS HATCHES ANY RUNWAY
SIMPLE OPERATIONS	STANDARD MISSIONS & PROCEDURES CREW FLIGHT PROFICIENCY MAINTENANCE COMMON DATA BASES HIGH LEVEL OF AUTONOMY
HIGH OPERATIONAL UTILIZATION	MINIMUM TURNAROUND TIME USE OF AIRLINE MAINTENANCE PROCEDURES MAINTENANCE SCHEDULING
LOW COST PER FLIGHT & LOW LIFE CYCLE COSTS	SUBSYSTEMS DESIGNED FOR MINIMUM MAINTENANCE INSPECTIBILITY & ACCESSIBILITY TO SUBSYSTEMS HIGH-RELIABILITY SUBSYSTEMS COST-OPTIMIZED BUILD RATE
OPERATIONS & SUPPORT EFFICIENCY	DESIGNED FOR ACCESSIBILITY & MAINTAINABILITY TRANSPORTABILITY BUILT-IN-TEST AUTONOMOUS OPERATIONS
ECONOMICALLY PRODUCIBLE	MANUFACTURING ACCESS EXTERNAL SYSTEMS INSTALLATION TPS INSTALLATION/REMOVAL

1.2.1 AMLS Launch System General Arrangement

The Langley-developed AMLS flight system is a two-stage system utilizing all LO2/LH2 propellants to minimize the handling of multiple propellants (Figure 1-3). All engines on both stages fire at lift-off with propellant being transferred into the orbiter from the booster during first stage operation. At separation, therefore, the orbiter has a full load of propellants. There are five derivative SSME engines on each stage; the system can, however, meet the mission success requirements with one engine out at lift-off on each stage. Both stages normally return to the KSC launch site although the orbiter is capable of returning to any major airfield within its 1100 nmi crossrange flight capability.

A unique feature of the system is the external payload canister concept. This innovative concept reduces the complexity of the orbiter structural design by eliminating the need to provide structural breaks for large payload bay doors. It also allows for future payload bay expansion, a feature not found in concepts with internal payload bays.

The crew of two and eight passengers of the orbiter (the booster is unmanned) are carried in an escape module during ascent and entry. This capsule provides assures crew safety from on-pad aborts to in-flight emergencies. During on-orbit operations, the crew "lives" in a workstation in the forward end of the payload canister. Rendezvous and berthing operations to SSF are carried out from this workstation.

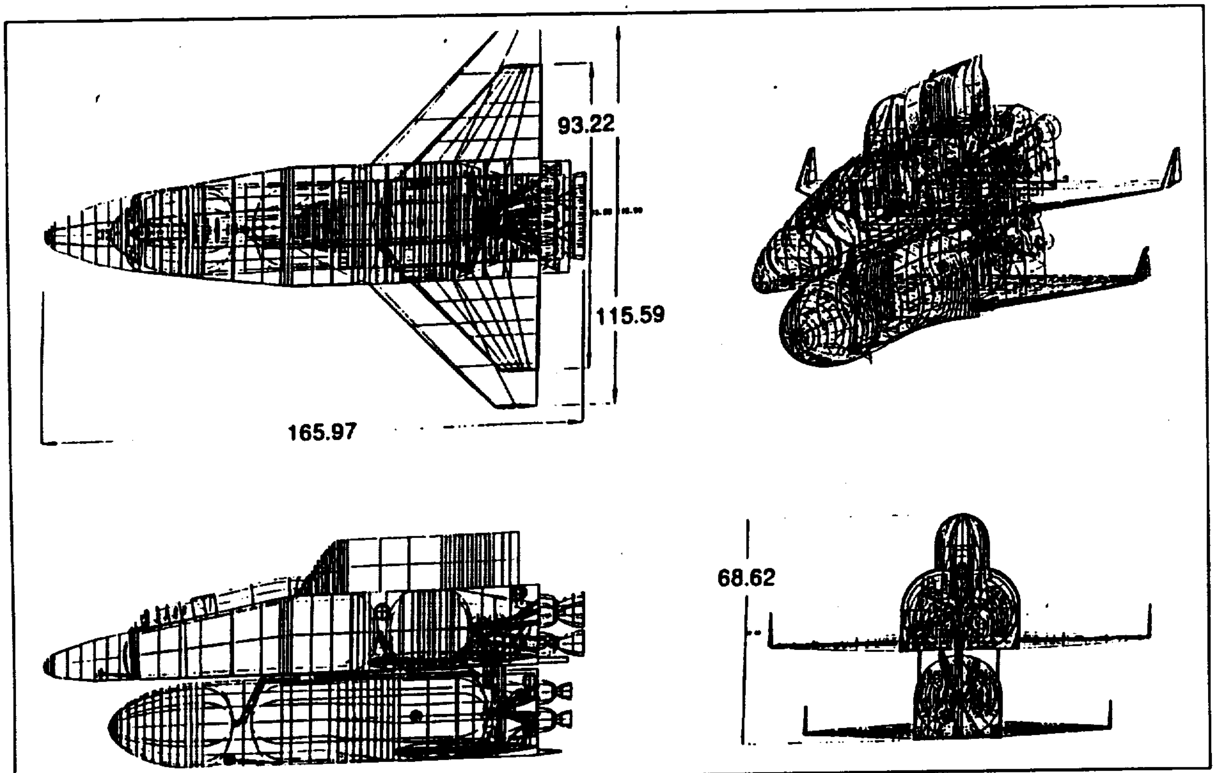

Figure 1-3. AMLS Launch System General Arrangement.

The AMLS system is roughly comparable in size to the Shuttle launch system. Figure 1-4 is presented to help the reader in visualizing the AMLS system, flight vehicles, manufacturing processes, and maintenance facilities and processing in the ensuing discussion. The principal differences are realized in the AMLS orbiter providing its own propellant after booster separation and the AMLS booster utilizing a far less dense propellant plus glide back aerodynamic surfaces.

The development of the AMLS concept has benefited from the combined experience of Rockwell and subcontractor participants. Given the broad objectives on operational efficiency, low life cycle costs, and crew safety, features have been provided enhancing accessibility for maintenance, enabling easy access for installation of subsystems during manufacturing, simple welds on FY 2000 material, transportability on 747-type aircraft, and subsystems enhancing the ability for efficient maintenance operations and

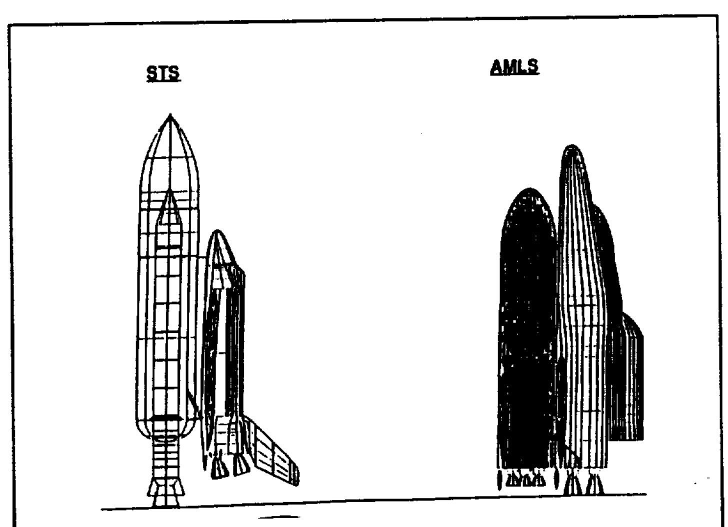

Figure 1-4. AMLS Is Comparable In Size to the STS.

turnaround. A major contribution to this approach continues to be the adoption of aircraft and airline approach to aircraft certification and flightworthiness: one-time certification and constant maintenance of flightworthiness as compared to the Shuttle's full recertification for each flight. The AMLS system has been designed to reflect this essential difference in philosophy -- recognizing that this is a major cultural change from the way we do business now.

- Performance trending
- Certified Airframe and Powerplant personnel
- Lifetime certification
- Operational environment

The design assures full interchangability of major components between vehicles to reduce spares requirements and ease processing schedules, incorporates "smart structures" systems for cryo tank leak and crack detection with means for internal inspection of tanks and intertank areas, and the repairability of structures and tanks.

1.2.2 Design Features Of Vehicle Concepts

The final configuration reflects the results of system design effort for maintainability and operability. We have incorporated a number of design features which contribute significantly to the operation and maintenance of the system as illustrated in Figure 1-5.

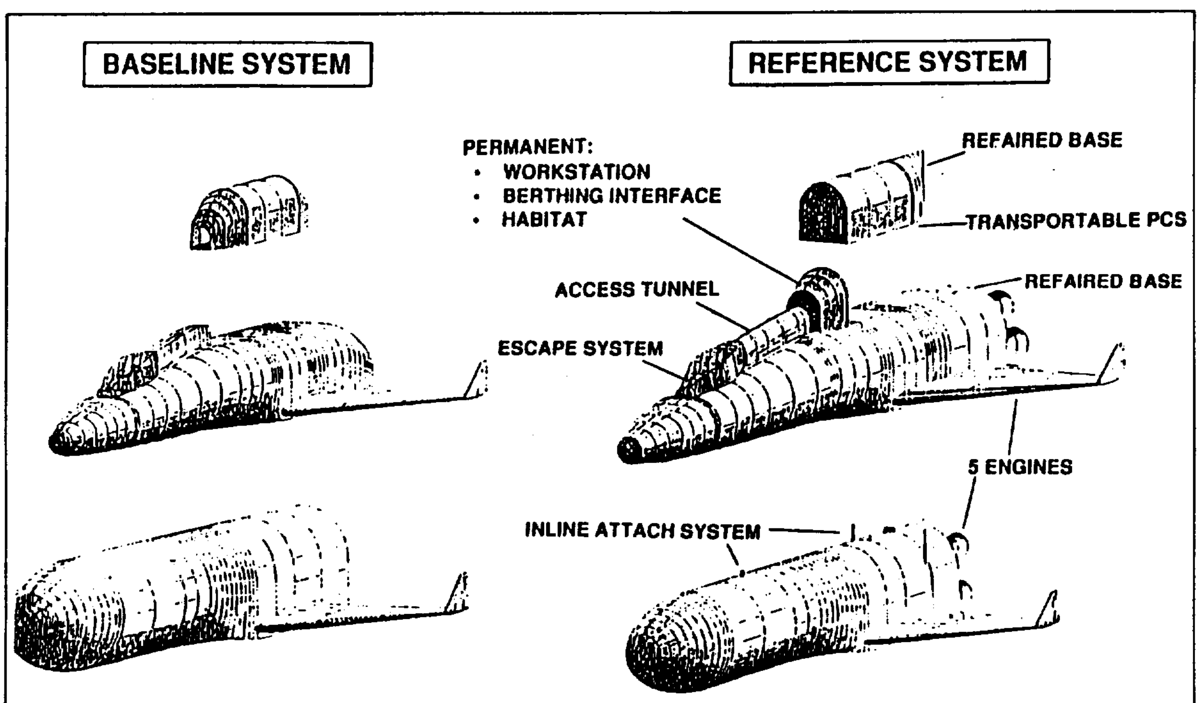

Figure 1-5. The Reference Configuration Reflects Results of System Design Effort for Maintainability and Operability.

These include:

- The PCS includes only the actual payload bay and the PCS base fairing: the fairing can be utilized by the user community for payload support equipment at their discretion as long as the payload weight and CG limits are observed.

- SSF berthing mechanisms are located in the PCS forward fairing. They will utilize the Shuttle/SSF interfaces existing during the Shuttle/AMLS parallel operations.

- The on-orbit work stations and living quarters are located in the forward PCS fairing combined with the SSF berthing system and payload bay access hatch. The tunnel area provides communication between the crew escape module and the work station area. An aerodynamic fairing will be used for ferry operations.

- All avionics systems in each stage are colocated on a platform that can be lowered to ground level for ease of access during servicing.

The development of the AMLS concept has benefited from the combined experience of our Rockwell and subcontractor participants. As a result, design legacies from these programs have been incorporated into flight vehicles. Given the broad objectives on operational efficiency, low life cycle costs, mission completion assurance, and crew safety, features have been provided enhancing accessibility for maintenance, enabling easy access for installation of subsystems during manufacturing, simple welds on conventional material, transportability on conventional aircraft, and subsystems enhancing the ability for efficient maintenance operations and turnaround.

A major contributor to this approach continues to be the use of aircraft and airline approach to aircraft certification and flightworthiness: one-time certification and constant maintenance of flightworthiness as compared to the Shuttle's full recertification for each flight. We have designed the system to reflect this difference in philosophy -- recognizing that this is a major cultural change from the way we do business now.

A major contribution from aircraft design practices is the need for inspection and repair of the cryo tanks and main engines. Large access hatches are planned for the tank domes to support insertion of space frames for inspection cameras and maintenance personnel. Body panels surrounding the engine compartment are non-structural and are easy to remove for access to the engines.

A full complement of subsystems has been defined for both the booster and the orbiter. These have been selected from a range of candidate options on the basis that they will provide the most cost-effective system when integrated. Some of the systems have been selected, such as the MPS-SSME-derivative, since they will have a thirty-year operating history plus periodic upgrading in the "normal" process of operation. Thus, we will be able to take advantage of this operational history to plan and schedule routine maintenance and minimize unscheduled and expensive servicing. Others, such as the avionics system components, have been selected on a similar basis but more with respect to their millions of operating hours in commercial or military aircraft. Such systems have, and will continue to have, a verified history of trouble-free operation. These will be "off-the-shelf" components having an already-demonstrated lifetime of operational robustness and reliability, an approach that, again, will go a long way to minimizing maintenance and operating costs.

1.3 OPERATIONAL SCENARIO

Operational benefits derive directly from design drivers that include accessibility, maintainability, maintenance evaluation, health monitoring, and the use of built-in test equipment. Ground, flight, and mission operations use standardized operations templates to reduce support resources needed to prepare the vehicles for the next flight. On board health monitoring during missions will provide a historical record that will be used to determine the required maintenance activities, both planned and unplanned. Following aircraft-type operational scenarios, only those systems requiring repair will be recertified -- other systems will be maintained in a flightworthy state. The use of licensed A & P personnel will reduce the number of skill mixes required, thus minimizing processing time and technician requirements.

The data developed during this study period included:

- Ground operations scenarios, facility requirements, software analysis, search and rescue analysis, processing timelines, manpower and associated staffing requirements, and GSE definition
- Flight and mission operations, mission analyses, staffing requirements, mission timelines, software analysis, and facility requirements
- Spare analysis, logistics sensitivity analysis, and logistics cost breakdown

Under the operating scenario developed (Figure 1-6), the orbiter and booster elements will arrive at the launch site landing strip from a returned mission or from the manufacturer on a carrier aircraft. Elements returning from a mission will be towed on their landing gear to the Horizontal Processing Facility (HPF) processing bays. Elements arriving from the manufacturer will be towed to the HPF mating bays for removal

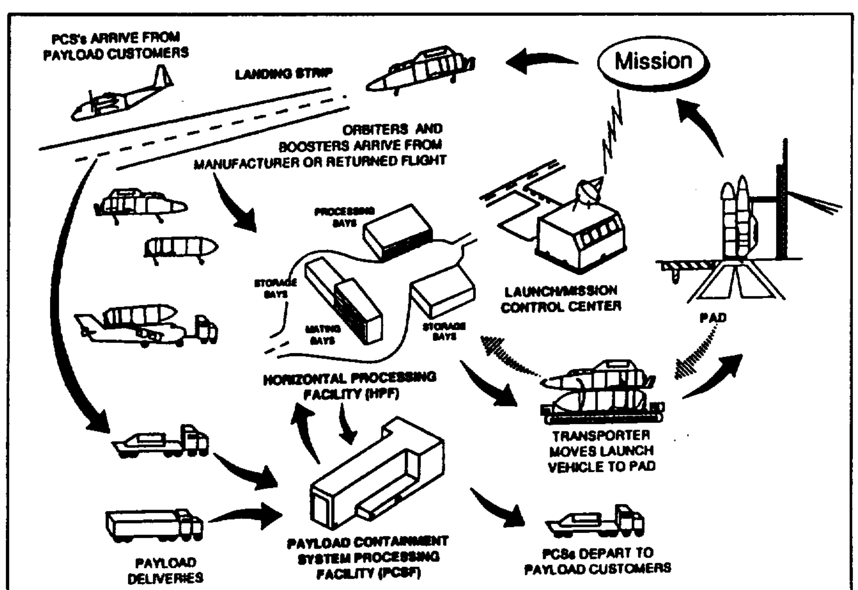

Figure 1-6. Operations Scenario.

from the carrier aircraft before they too are transferred to the processing bays.

Elements will undergo processing operations indicated by on-board health monitoring flight data. After preparation for integration with the other AMLS elements, the elements will be towed to either a mating bay or to a storage bay.

Integration of the AMLS vehicle will begin with the positioning of the transporter in a mating bay. A booster element will be lifted and mated onto the transporter. Next, an orbiter element will be positioned next to the booster/transporter, lifted, and mated to both the booster and the transporter. A PCS, which has undergone checkout and verification in the PCS Processing Facility (PCSPF) will be lifted and mated to the orbiter. The PCS mating operation is the final operation performed before the AMLS vehicle is transported to the launch pad. This minimizes the time the payload can not be accessed.

The vehicle will be transported to the pad, where the supporting structure of the transporter will be mated to the in-place erection mechanism. The mechanism will rotate the vehicle to vertical and umbilical and interface connections will be made. The transporter will be returned to its horizontal position and removed from the pad area. Operations at the pad are minimal and include propellant loading, pyro arming, and crew ingress.

The new American Airlines Maintenance base under construction at Alliance Field, Fort Worth (Figure 1-7) is representative of the type of conventional construction that we are projecting for the AMLS maintenance base at KSC. The design is standardized and requires little new development other than that required for the particular application. The main building features a totally unobstructed working area with, again, commercially available workstand designs that are easily moveable to wherever needed. The back shops are close-in and accessible during all maintenance operations.

Figure 1-7. American Airlines Maintenance Facility Represents the State-of-the-Art in Facility Design.

1.4 TECHNOLOGY ASSESSMENT

In order to minimize development costs and risks, our principal technology groundrule specifies that all technologies reflect a NASA Technology Level of 6 or better. This implies that the individual components or brass-board models must have been tested in a relevant environment. The groundrule further specifies that this technology level must have been reached by the year 2000.

An extensive database of technology development requirements was reviewed. These developments range from the NASA Space Technology Plan and the Air Force's Military Space System Technology Plan to the National Launch System and the National AeroSpaceplane (NASP). These resources, coupled with airline-oriented technologies identified by Johnson Controls, have provided a comprehensive list of available and emerging technologies that will either be available now, fully matured by 2000 in their current development cycles, or whose development can be economically accelerated to reach the required maturity levels with minimum risk.

It is recognized that not all of the technologies presented in Figure 1-8 have to be fully matured at an early stage of the system development. Some are needed early on because the system design in dependent on them, e.g., TPS and the primary structural materials. Others can be brought into maturity later although at an increased technology risk.

Applicable technologies where identified early in the study in order to identify to the system developers just what technologies could be expected to be available in the reference time frame. This time frame is centered on the FY 2000 technology readiness date established for this study. Some technologies are currently state-of-the-art while others require considerable acceleration in order to be available and fully matured by the time they are required.

As in the case for the PLS, there are no enabling technologies -- that is, there are no "breakthroughs" required and the system could be developed with existing technologies with enhancements. However, performance will be enhanced and operational costs will be minimized by capitalizing on the advancing state of new and emerging technologies to make it worthwhile from a LCC standpoint.1

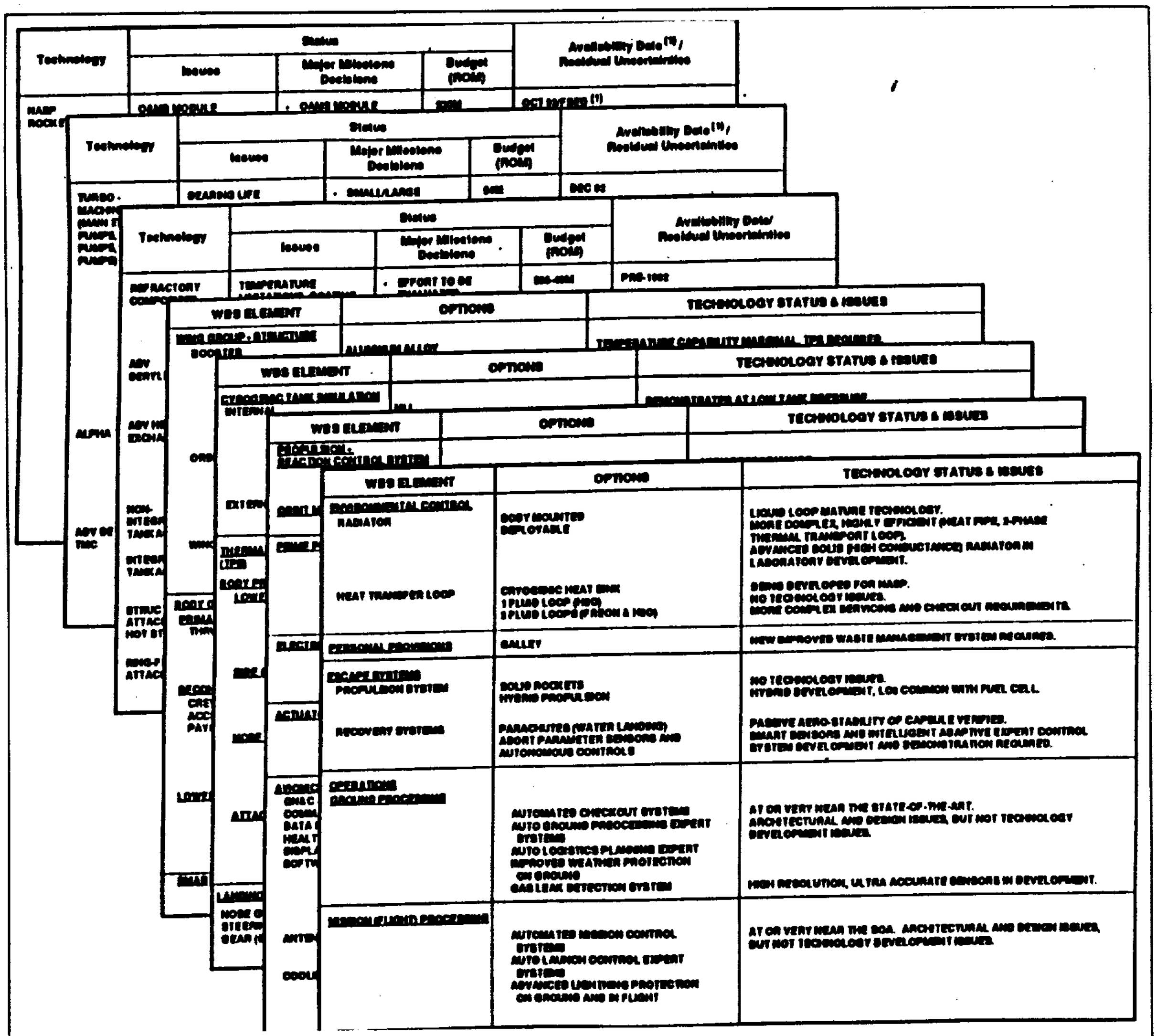

Figure 1-8. Technology Options.

1.5 MASTER PROGRAM SCHEDULE

The Master Program Schedule (Figure 1-9) outlines the sequence of major events in the development of the AMLS concept through to IOC. Major milestones beginning with ATP for Phase B are shown. The manufacturing schedules include lead times for procurement of material and vendor parts as well as in-house manufacturing and assembly, test, and validation.

Structural and component tests will verify the design of those elements. The need for a long term dynamic test program (test to failure) as conducted for aircraft is still being evaluated; the low flight rates for these vehicles may preclude the need for such tests.

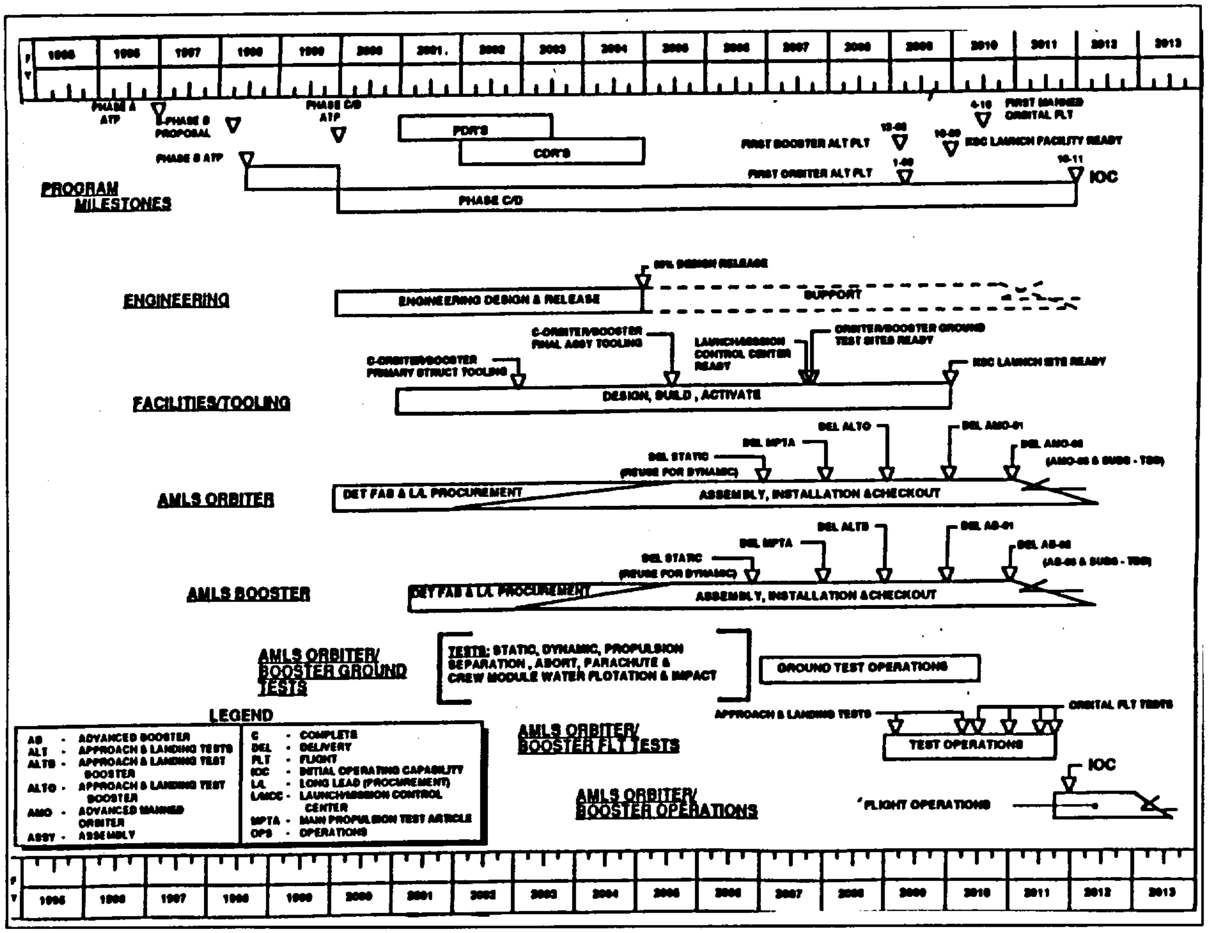

Figure 1-9. Summary Master Program Schedule.

The approach and landing (ALT) flight test program includes full scale low speed tests launched from a 747. These tests include unpowered approach and landing tests. These tests are designed to verify the post-entry handling qualities, landing performance, and the guidance and control and autoland systems. The orbital flight tests complete the flight test series by verifying the overall operational capability of the full system over a wide range of potential operating conditions.

1.6 SUMMARY

The AMLS, for the purposes of this study, is seen as a replacement for the Space Shuttle system. After a phasing in period, it could provide much of the up and down-cargo and personnel transportation during its period of operation, complemented by the PLS and NLS. Other alternatives exist or may exist to provide future transportation, but they are not a consideration for this study. The principal focus of this study has been on the development of the operationally efficient AMLS system concept and the identification of technologies that may be required for the system concept to realize its full potential in terms of LCC effectiveness.

This document reviews the achievements of our work under Task Assignment 3, the Advanced Manned Launch System. We present a detailed "snapshot" of the final system concept and the decisions we have made and their rationale. The same cost-efficient operational and design philosophy we used in the development of the PLS concept has been employed here augmented by considerations harvested from the design and operation of very large aircraft. We have incorporated an extension of aircraft methodologies to large reusable aerospace systems into the system concept and, in the process, we have defined most subsystems, manufacturing, and operational scenarios. The data we have developed has been assembled into an electronic database in order to provide ready access to a multitude of data. These files include mass property data, manufacturing methods and facilities, development tests and facilities, test articles and facilities, and the technology status on each WBS element.

2.0 SYSTEM DESIGN PHILOSOPHY AND STUDY GROUNDRULES

This section documents the groundrules used throughout the study. They consist of general groundrules used to perform both the overall study tasks and documentation requirements specified by NASA, mission design groundrules for mission planning and design, subsystem design groundrules for the AMLS system, and operations and support groundrules for ground operations. These latter groundrules are program-level and project-level requirements, from which lower level requirements are specified in a subsequent requirements/allocation process. The payload containment system groundrules are included to establish the AMLS Program approach to processing payloads.

2.1 STUDY GROUNDRULES DEFINITION

The following sections provide the study groundrules that form the basis for performing the analytical and documentation activities for this study.

2.1.1 General Groundrules

The general study groundrules presented in Table 2-1 were derived from NASA AMLS documentation, study Task Assignments 1 and 2, and groundrules presented at the time of the Task 3 kick-off meeting on November 29, 1991. They are distinguished from the other groundrules in that these general groundrules are derived from the overall study objectives and government direction on assumptions or methods used to conduct the study. They establish the overall framework from which the Task Assignments are performed. On the other hand, the design groundrules presented in Section 2.2 establish the top-level requirements used in defining the AMLS operational system.

Six of the eight study groundrules were extracted from the AMLS Groundrules Documentation, Reference 2-1, provided by NASA LaRC. Of these, the first groundrule in Table 2-1 (specifying that the AMLS should be a low-cost, operationally efficient system, with 30 year operational life) is derived from the overall objective of the study. Design evaluations to be performed during the course of the study are traceable to this groundrule. In addition to nominal life-cycle-cost estimates over an agreed upon milestone and operational schedule, a cost risk estimate is required along with cost/benefit analyses for each major technological and process innovation to be incorporated later into the final preferred design. The latter data provide the cost arguments for the innovations by providing the negative cost impacts that could be felt by a nominal AMLS program if a particular innovation was not incorporated.

Specification of the IOC goal enables the determination of the schedule for important program milestones. It also has an indirect influence on the test program type and duration which must be performed to demonstrate with a high confidence level achievement of the maintainability and reliability goals. The ATP for Phase C/D which corresponds to an 2010 or beyond IOC goal will be derived from the study based on a development schedule which provides a low risk, low cost development program.

Table 2-1. AMLS Study General Groundrules

1. The AMLS is the manned replacement for the Space Shuttle with an IOC date between 2010 to 2020. It shall: o Demonstrate low life-cycle cost and low cost-per-flight. o Be capable of safe and reliable vehicle operations. o Incorporate the use of operationally efficient systems. o Be robust system with timely response. o Have an operational life of 30 years.
2. Only minimal moldline changes to the AMLS booster and orbiter moldline to improve the design or increase the internal volume shall be incorporated.
3. All elements of AMLS shall be manrated according to the guidelines set forth in JSC-23211 "Guidelines for Man-Rating Space Systems" with spacecraft systems designed for fail operational/fail safe operations.
4. The system design will accommodate DRM 1, but it will not preclude other possible missions such as satellite servicing and repair, delivery, rescue, etc.
5. The AMLS shall use proven state-of-art cost-effective technologies at NASA technology level 6 or better and be available on a date consistent with the expected IOC date. Some system elements may have an earlier IOC than the complete system.
6. AMLS system includes all flight hardware, ground and flight systems, facilities, and personnel.
7. The AMLS shall not produce any long lifetime orbital debris.
8. All unique AMLS facilities at the launch site are new.
9. All AMLS program data shall be presented in Standard English Units.

The development of credible cost and schedule estimates are necessary to provide design and program decision information. Groundrule 4 defines that the prime mission will be transportation of passengers and cargo to and from the Space Station. Alternate missions capability for servicing, repair, on-orbit delivery and rescue will not be excluded by the design.

Groundrule 2 provides that the overall AMLS booster and orbiter moldlines defined by NASA will be retained as much as possible throughout this Task Assignment. Exceptions to this are the potential to locally scale-up the geometry of the vehicle to increase the internal volume capability or include TPS beyond the IML. Such geometry modifications, however, shall have minimal affect on the existing aerodynamic/aerothermodynamic characteristics for the AMLS vehicles.

Groundrule 3 addresses the fact that the AMLS vehicle is to be manned. This requires that all elements be man-rated, affecting the design of all hardware of the system. It requires that the hardware design has appropriate safety factors for adequate design margins, high reliability, and minimal hazardous or highly toxic materials. It also requires quality assurance methods, redundancy in critical systems, and a level of fault tolerance, specified as fail-operational/fail-safe for the AMLS. This is required for crew safety, as specified in applicable documents such as JSCM 8080 (Manned Spacecraft Design Criteria and Standards), and JSC 17481A, Safety Requirement Document for JSC Space Shuttle Flight Equipment.

The required technology level, Groundrule 5, helps determine the number of options available to the subsystem designer when attempting to satisfy functional requirements within cost and schedule risks constraints. The requirement for AMLS is NASA Technology Level 6 or better to support the AMLS IOC date. This requires that the component or a brass-board model has been tested in the relevant environment. As a point of comparison, the following provides the definition for the various technology levels:

- Level 1 Basic principles observed and reported
- Level 2 Conceptual design formulated
- Level 3 Conceptual design test performed analytically or experimentally
- Level 4 Critical-function breadboard demonstration
- Level 5 Component or brass-board model tested in relevant environment
- Level 6 Prototype or brassboard model tested in relevant environment
- Level 7 Engineering model tested in space
- Level 8 Baselined into production design

Typically, the first three technology levels are considered technology development while the fourth to seventh level are advanced development. Technology Level 8 is off-the-shelf technology, which could be modified to satisfy unique design requirements.

Groundrule 7 was added to establish that the system shall not produce any orbital debris. A growing concern for designers of spacecraft in low earth orbit is the increasing population of man-made debris in earth orbit. This debris ranges in size from small particles to large upper stages and nonfunctioning satellites and is distributed nearly uniformly in orbital inclination in low orbits (less than 250 NM). Concern stems from the significant damage fact that even small particles can do to spacecraft. The probability of such impact increases with the size and duration of a satellite in low earth orbit -- characteristics that apply to Space Station. An effective way to prevent the increase of this population is to design upper stages, spacecraft, and separation devices to preclude the generation of debris. This is a policy that NASA has agreed to pursue.

All facilities at the launch site will new, Groundrule 8. No overlap with the Shuttle facilities will be addressed in the current Task.

2.1.2 MIL-STD Tailoring

DRD's 3, 4, 5, and 6, presented in the study task statements, referenced specifications to be applied when responding to the data request. A tailoring exercise was performed for each referenced military specification. The results of these tailoring activities are presented in Reference 2-5. When reviewing the application of the specifications to the requested data within the DRD, it was understood that the specification tailoring establishes the organizational content with which the DRD submittal will comply only for this pre-Phase A study.

As a means to initiate the tailoring activity, DOD-HDBK-248A ("Guide for Application and Tailoring of Requirements for Defense Material Acquisitions") was reviewed. This document provided general guidelines and a suggested format to perform the tailoring exercise. In addition, Appendix B of Rockwell's ALS Phase 1 System Design Data Package, which provided specification review sheets from the ALS specification tailoring exercise, was reviewed. Using these documents as guides, a specification tailoring template was developed. Each task leader reviewed the appropriate specifications and recommended modifications or deletions to specification paragraphs with an appropriate rationale. Appendices within several specifications provided a guide to assist in the tailoring by identifying the paragraphs that are appropriate for various program phases. Where these inputs were available, they were used to justify appropriate paragraph deletions.

In compliance with DRD 3, specifications DoD-STD-100C and MIL-STD-490A were reviewed and tailored. The results of this activity are summarized and presented in Attachment 1 of Reference 2-5. The drawing practices defined in DoD-STD-100C are adopted as specified, with the exception of the use of English units for the new AMLS design. The CAD-produced drawings will use the Rockwell version of the various ANSI Y14 drawing format conventions since it is part of the installed software package. These variations are few and minor. The AMLS vehicle/subsystem description will follow MIL-STD-490A, Type A (System/Segment Specification) except for sections pertaining to the requirements of production and delivery of hardware. The paragraphs of the specification MIL-STD-490A other than those relating to the characterization of the AMLS vehicle and system will be top level in nature.

DRD 4 requests an Acquisition Plan which extends from concept development through the operational phase of the AMLS program. Tailoring of the referenced specifications will be an on-going process as part of refining the acquisition plan prior to the initiation of the next AMLS program phase. Several of the referenced specifications such as MIL-STD's-1547A, 1546A, 1540B, DoD-STD-167A, and MIL-Q-9858A are applicable to hardware, and such, will be deferred until hardware procurement in program Phases B, and/or C/D. Specifications which are applicable to a pre-Phase A type study with the appropriate tailoring are those pertaining to program management, or system engineering, such as MIL-STD-483A. The suggested tailoring of these specifications is presented in Attachment 2 of Reference 2-5. In addition, a review of manufacturing oriented specifications typically used at Rockwell resulted in the suggestion that MIL-STD-1528A "Manufacturing Management Program" be included in the set of specifications used as a guide for this study phase. A tailoring exercise was performed on this specification with the results also presented in Attachment 2 of Reference 2-5.

Attachment 3 of Reference 2-5 provides the recommended tailoring of MIL-STD-1388-1A (Logistics Support Analysis) to support DRD 5. The major change in the documentation level reporting is Task 401. This task is normally not required during this phase of a program; however, in-house military aircraft data and STS orbiter data will be used as a point-of-departure to determine task requirements for the cost and operations estimating activities. The remainder of the task definitions were chosen at the level that would normally support a conceptual-development type of analysis. The MIL-HBK-266(AS) requirements are addressed by the Reliability Centered Maintenance (RCM) activity per MIL-STD-2173(AS), as modified in Attachment 4 of Reference 2-5. This activity is to be closely coordinated between the logistics and reliability/maintainability organizations during the Logistics Support Analysis (LSA) process. RCM factors that drive operations support (MTBF, MTTR, and Availability) are to be evaluated for each subsystem to determine their impact on support and logistics and to identify trades that are required for determination of optimum repair levels/procedures.

The reliability and maintainability standards were reviewed for this effort and are also included in Attachment 4 of Reference 2-5. MIL-STD-1629A will be tailored to include RCM as adopted by the airlines' Maintenance Steering Group (MSG). All references to weapon system applications are deleted from this analysis. A Failure Modes and Effects analysis (FMEA) will be performed on selected high maintenance system/subsystems scheduled for investigation to a Phase B level. These specific systems/subsystem studies will provide additional insight into the reliability, maintainability, and maintenance philosophies being applied to the AMLS design process. Abbreviated Reliability Centered Maintenance (RCM) shall also be the integration of design and maintainability engineering and the development of design driven maintenance programs.

- MIL-STD-470A data will cover only those task numbers that apply to this preconcept phase.

- MIL-STD-1543A will include most of the tasks that are evaluated at a Phase B level of documentation.

- MIL-STD-785B will be selectively applied in most of the tasks (except where detailed design data or plans are needed).

- MIL-STD-2173 (AS) will support the RCM activity and also supports MIL-STD-1629A. Only minor modification is required until Paragraph 4.2.2 where detailed hardware and operations data would be needed. This standard will support MIL-HBK-266(AS)-type activities.

2.1.3 Adoption of Airline Specifications

During the pre-Phase A period, an Airline Transport Association (ATA) coding system, ATA-100, was studied for possible tailoring to the AMLS systems and operations in support of system design breakdown and WBS. This system will provide tracking capability for schematics, maintenance manuals, maintenance specifications, part number system, FMEA, MSG, procurement specifications, design specifications and technical correspondence during the active life of the system.

Additional areas of review not applicable to pre-Phase A which would be included in future program phases include Aeronautical Radio, Inc. (ARINC) specifications. ARINC provides standards for all major aircraft vendors line replaceable unit (LRU) venders and airline engineering departments. These include design specifications for various types of connectors,interface configurations, environmental requirements, and racking configurations. Other areas of future study shall include application of ATA 300 to the AMLS. This specification provides standards for the shipping, handling and storage of flight and GSE hardware including standardization of containers.

2.2 DESIGN GROUNDRULE DEFINITION

Design groundrules shown in subsections 2.2.1 through 2.2.4 establish the important program- and project-level set of requirements for the requirement allocation process. Since the AMLS Groundrules Document, LaRC Kickoff Meeting Briefings and Government Furnished Data (References 2-1, 2-4, 2-6, and 2-7) provided by NASA established a thorough listing of groundrules applicable to AMLS, the majority of recommended groundrules in this section were extracted from these documents. The Payload Container System (PCS) study final report, Reference 2-7, was reviewed to insure subsection 2.2.4 is complete. Vol. X, Flight and Ground Systems Specification (Reference 2-2), and the Shuttle-C Requirements Document (Reference 2-3), were also reviewed as a means to ensure that a comprehensive set of groundrules is established.

Conclusions from prior applicable studies listed in Table 2-2 were also used, either to recommend a new groundrule or to justify an existing one. Many of the reviewers selected to perform this review task were either program managers or heavily involved with these studies. Others are aware of study results as a means to stay abreast of developments in their areas of expertise. The results of this study review activity indicate that the majority of findings from prior studies support the AMLS groundrules presented in Reference 2-1. New groundrules in this section that are traceable solely to results of prior studies are those pertaining to adequate spares and airline-type operations.

As the WBS numbering system matures, these groundrules and the lower level requirements will be correlated with the appropriate cell in the three- dimensional WBS matrix proposed by NASA. This will permit tracing a change in a groundrule (or lower level requirement) to the set of WBS data templates (hence, cost) that may be affected by this change. PC-based system engineering tools, such as the commercial "4th Dimension" program, are being evaluated as the method to store and manipulate requirements to support the systems engineering activity. Once this tool is established, the groundrules shown in this section will be entered as the top-level requirements.

When defining groundrules, a typical issue that must be addressed is whether a groundrule is actually a lower level requirement. Since this is usually subjective, rationale is provided to justify each proposed groundrule. The following paragraphs provide such rationale for each proposed groundrule.

2.2.1 AMLS Mission Design Groundrules

The groundrules presented in Table 2-3 relate to the mission planning and design, crew training, etc that is normally conducted at NASA/JSC.

Mission Definition. Specification of design reference missions (DRMs) are important to the design of the system, especially that of the flight vehicle, since they guide the further definitions of many of the functional requirements. In particular, they guide the sizing of the spacecraft power, propulsion, and life support systems and provide the basis for the booster performance requirements. For this task, only DRM-1 is considered. This DRM requires the AMLS to provide delivery of passengers and cargo to and from the Space

Station. This also implies that the orbiter design must be compatible with Space Station requirements. In addition, reference missions also serve as an operations baseline against which the vehicle design can be measured. Implicit in the 72-hour mission duration of DRM-1 is that 2 crew and 8 passengers will enter the SSF following docking and the orbiter will operate autonomously requiring no support or services from the Space Station. Critical systems functions which will allow the AMLS to remain functionally independent of SSF will remain active during this docked phase. The 35 mandays capability incorporated in the AMLS orbiter design shall not preclude alternate missions.

The booster will be unmanned, but recoverable, with the capability to return to a horizontal landing at the launch site runway after separation from the orbiter.

Vertical Lift-Off. The booster and orbiter are design for vertical lift-off from the launch pad.

Enhanced Launch Probability. The AMLS design will have sufficient margin to allow launch during non-seasonal winds and marginal weather conditions that will still support the return of the booster to the launch site runway. The system design will also support night as well as day launch with capability to perform all abort modes, plus night landing at the launch site runway.

Launch probability is dependent on AMLS design margins and launch site weather statistics. By designing the flight vehicle to be able to launch under adverse weather conditions (temperature, wind, and rain), its ability to meet target launch dates and launch windows is significantly increased. An advantage of having the AMLS launch site at KSC is that extensive weather statistics are available to establish accurate weather requirements. This requirement will be an important design consideration for the design of the AMLS flight control and guidance hardware and software. The ability to launch (and to recover, following an abort) at night will also increase launch probability and will potentially reduce the length of launch delays.

Autonomous Launch Azimuth. The on-board computers and navigation systems will accommodate early or late launches and still optimize the ascent trajectory to obtain maximum to-orbit weight performance.

Table 2-2. Prior and On-going Studies Reviewed to Assess AMLS Groundrules

NASA Shuttle II Study
NASA LaRC AMLS Study
Advanced Manned Launch System Study, PLS Tasks, September 11, 1990, Rockwell International. Contract NAS1-18975, NASA/LaRC
Conceptual Design Study for a PLS, December 4, 1990, Boeing, Contract NAS9-18255, NASA/JSC
Shuttle Ground Operations Efficiencies/Technologies Study, March 21, 1989, Boeing, Contract NAS10-11344, NASA/KSC
Operationally-Efficient Launch Site (OELS) Study Final Report (05-88-KSC-016), October, 1988, Vitro Corporation, Contract NAS 10-11436, NASA/KSC
Advanced Launch Systems (ALS) Design Study, Phase 1 System Design Review (STS 88-0686), June 1988, Rockwell International, Contract F04701-87-C-0139, AF/SD
Space Transportation Architecture Study (STAS) (STS 87-0532), November 16, 1987, Rockwell International, Contract F04701-85-C-0158
NASA/JSC Design Goals and Technology Requirements for Future Launch Systems Final Report (88-187), April 19, 1988, Eagle Engineering/ LEMSO, Contract NAS2-17900, NASA/JSC
Air Force Structural Definition Study, Contract F33615-87-C-3243, Rockwell International, 1987
National Aerospace Plane (NASP). Contract F33657-86-C-2127, AS/NASA Joint Project Office
Space Transportation Main and Booster Configuration Studies, Phase A, NASA/MSFC
Reducing Launch Operations Costs (New Technologies and Practices) (OTA-TM-ISC-28), September 1988, Office of Technology Assessment
Assured Crew Return Vehicle (ACRV), System Performance Requirement Document (SPRD), JSC 34000, November 6, 1990
Advanced Manned Spaceflight Capability (AMSC) Technology Identification Study, AFWAL-TR-83-3055, Rockwell International, Contract F33615-81-C-3033, June 1983, AFWAL
STS Evolution Study, July 1989, Rockwell International, Contract NAS9-14000, Schedule E, NASA/JSC An Assessment of Alternate Thermal Protection System for the Space Shuttle Orbiter, STE 81-0549, February 18, 1982, Rockwell International, Contract NAS1-16302
NDV Space Transportation Comparison Study - Task 11, Rockwell International, Contract F33657-86-C-2127, January 20, 1989
Launch Operations Concerns and Operation Enhancing Technology (Propulsion), October 26, 1990, NASA Project Office, MSFC, ALS 90-80
STEP Phase B Design Concept Review, July 9-13, 1990, Rockwell International, ALS90-53
Integrated Hydrogen/Oxygen Technology (IHOT) Applied to Auxiliary Propelsion Systems, September, 1990, Rockwell International, Contract NAS3-25641, NASA/LeRC

Table 2-3. AMLS Mission Design Groundrules

1. The AMLS shall be designed to accomplish DRM 1 as follows: Orbiter o Two crew and eight passengers to and from the Space Station at 220 NMI (262 NMI MAX) at 28.5 deg. inclination. o 72-hour mission duration with 12 hour for contingency (35 man-days) o OMS Delta Vel. of 1350 FT/SEC for orbital maneuvers plus 40 ft/sec reserve. o RCS Delta Vel. of 150 FT/SEC for attitude control plus 45 ft/sec reserve. o Deliver and return a 15-ft diameter by 30-ft length payload, with max weight of 40,000 lbs. Booster o Unmanned with glideback to launch site runway. o RCS Delta Velocity of 40 FT/SEC for attitude control plus 8 ft/sec reserve.
2. The orbiter and booster will be designed for vertical lift off.
3. The AMLS shall have an enhanced annual launch probability compared to STS due to weather constraints. The AMLS vehicle shall also have night launch and landing capability.
4. The vehicle shall have autonomous variable launch azimuth capability to execute all acceptable launch-to-insertion azimuths for KSC.
5. The AMLS orbiter shall be the active vehicle when docking with Space Station, but will also have the provisions to allow berthing at a Space Station node using Space Station handling equipment. Both manual and automated control capability will be provided for active docking. Minimal RCS plume impingement and contamination effects on the Space Station or other orbiting element is required.
6. The vehicle shall have autonomous operations while docked to Space Station Freedom, requiring no support or services.

Docking. In order to achieve Space Station crew rotation as specified in DRM-1, the orbiter will be capable of docking to Space Station. This requires rendezvous maneuvering, a docking mechanism compatible with Space Station and proximity operations. An alternative to a hard-docking system is using a berthing technique with manipulator arms providing the final closing maneuver. Since the AMLS will be manned as specified in DRM-1, it is anticipated that the orbiter shall be capable of automatic or manual docking with man in the loop. The orbiter will accomodate berthing with the Space Station handling system. The orbiter proximity opeations control system will minimize the propelsion plume impingement on the Space Station elements.

Autonomous Operations. The AMLS will impose no additional subsystem loads on the Space Station except for support of the transferred crew and cargo transfer and berthing to the required node.

2.2.2 AMLS Subsystem Design Groundrules

The groundrules in this section, Table 2-4, address the configuration of the subsystem design.

Autonomous Vehicle Operations. The ability of the AMLS vehicle to perform autonomously (i.e., independently) from ground mission control has significant implications for the design and operations of several AMLS functional areas and vehicle subsystems such as GN&C, data processing, and health monitoring. Synergy exists with the capability and reduced ground check-out during vehicle processing due to having on-board fault detection and isolation at the component level.

Table 2-4. AMLS Subsystem Design Groundrules

1. The AMLS vehicle design shall have autonomous operations from pre-launch through landing within the limits of program constraints. Mission sequences shall be automated with crew take-over capability.

2. Aircraft-like subsystem design approaches and methodologies shall be applied where possible to insure efficient long term operations. The vehicle designs will provide easy access for maintenance and inspections.

3. Where on-the-pad emergencies dictate rapid, but orderly evacuation of the AMLS vehicle, the vehicle and ground support facility design shall allow emergency egress of all crew and passengers to a safe area in a maximum of three minutes from notification.

4. The AMLS shall have continuous escape/abort capability from the time of crew access arm retraction through ascent, on-orbit operation, and following entry where a safe utilization of the crew escape system is available. After liftoff, the AMLS system shall provide for intact recovery of the vehicle and crew under the widest possible range of failure scenarios.

5. AMLS elements with return-to-launch-site (RTLS) capabilities shall provide for depletion of onboard propellants prior to an intact landing.

6. Recovery systems on the crew module shall engage automatically to provide a safe environment for the crew until rescue. The egress hatch shall be oriented above the water line for water recovery and accessible for land landing. The AMLS orbiter design shall provide for quick crew egress following an abort autonomous of ground crew support. This capability shall exist for both night and day, and in all weather conditions.

7. The escape and water impact accelerations on the crew following ascent escape will not exceed the following values:

	X (g's)	Y (g's)	Z (g's)
Escape	8	-	-
Water Impact	15	10	5

8. The orbiter accelerations shall not exceed the following values:

	X (g's)	Y (g's)	Z (g's)
Ascent	4	4	.0.5
Entry	<2	1	0.5
Landing	1.8	1.5	4.2
Landing (Emergency)	4.5	1.5	4.5

The product of load factor and time shall not be detrimental to deconditioned SSF personnel. The emergency landing conditions are the extreme contingence case.

9. The AMLS orbiter shall have a landing crossrange capability of at least 1100 NMI. All elements will be able to land on an 11,000 ft long runway in daylight or at night using available landing system such as MLS (microwave landing system etc.) or other external GN&C assets. All elements shall have the capability of crosswind landings in winds at an angle of up to 90 degrees from the landings path axis and at 25 knots velocity.

10. The system design will allow a single main engine failure, that shut-down safely, on each flight element and still satisfy the mission requirements.

11. A common propellant will be used for all AMLS propulsion systems.

12. The AMLS orbiter shall have an airlock system for on-orbit crew transfer to and from an unpressurized payload bay (EVA), to and from the Space Station and for space rescue. The airlock and tunnel hatch configuration will insure the return of all crewmen to the crew module under all failure scenarios.

13. EVA provisions for two trained crewmen shall be provided and personnel rescue systems for on-orbit survival and intercraft transfer for all other personnel.

14. The AMLS crew module internal volume shall accommodate all flight personnel (5 to 95 percentile) wearing partial pressure suits.

15. The AMLS spacecraft manned area shall have a 10 to 15 PSI N2/O2 atmosphere. The crew module shall be capable of two purges and two repressurizations per mission.

Although the vehicle is capable of automatic operation throughout all mission flight phases, the ability of the flight crew to command and monitor automatic mission sequences and to take over active control will be provided. Automated mission sequences which will have crew monitoring and take-over capability are pre-launch, launch to the desired orbit, abort, performing necessary on-orbit maneuvers including docking with the SSF, executing the de-orbit burn, entry, and approach and landing at the selected landing site.

Vehicles Designed For Ease Of Maintenance. Designing for ease of maintenance reduces turnaround time and launch delays due to equipment failures. This requirement affects the design of all vehicle subsystems by ensuring that they are easily accessible and repairable. This will result in the use of built-in test equipment, modular subsystem components, low-maintenance TPS, and the elimination of hydraulics and APU's. This requirement also has implications for the allocation of mean time before failure and mean time to repair.

Quick Crew Egress. A lesson learned from the Apollo program is the importance of a manned spacecraft to provide quick egress of flight personnel on the launch pad and following landing. This is especially true for aborts in which conditions may exist where egress is critical for flight personnel survival. This is an important consideration in the orbiter design (specifically hatch size and location) and has obvious safety implications.

Continuous Abort Capability. A significant flight crew safety issue is the ability of a manned flight vehicle to safely perform aborts. The requirement for continuous abort capability maximizes the probability of safe crew return. This will necessitate the capability for on-the-pad aborts. This groundrule has a direct impact on the design of the abort and recovery subsystems hardware and software and the ground recovery operations.

Deplete Propellent For RTLS Abort. The orbiter will be designed for landing with maximum payload weight, 30,000 pounds plus passengers and crew, and empty propellent tanks. During an Return-to-Launch-Site (RTLS) abort, the booster and orbiter design must incorporate means to deplete the main engine fuel prior to approach and landing at the launch site landing strip.

Recovery Systems. The safe recovery of the orbiter and flight personnel following nominal and aborted missions is an important consideration for the design of the orbiter and recovery operations. To ensure that this is accomplished, this capability must be provided for land and water, day and night, and a wide range of weather conditions. The ability to automatically engage appropriate recovery systems on the AMLS such as location beacons and stabilization devices enhances crew safety, especially following an abort or landing at a remote site. The stabilization floatation devices must be sufficient to expose an access hatch following water impact.

Vehicle Accelerations. The maximum accelerations during operations are significant factor in the vehicle structural design. The structural margins will support the launch during non-nominal wind conditions without impacting the design or mission planning. The maximum values for ascent are consistent with the Space Shuttle design and would be controlled by throttling the main engines during the ascent period.

Crew Accelerations. The maximum accelerations and exposure times to accelerations are important considerations for crew safety. Nominal mission entry and landing phases were chosen to be acceptable for deconditioned crew personnel, Reference 8. The peak values for launch escape and water impacts, both of which would be encountered only during aborts, are of very short duration and will most likely never be subjected to deconditioned crew personnel. The crew compartment separated with the crew will be designed to withstand these G levels.

Landing Capability. The requirements for landing capability are important to both flight vehicle design and landing site characteristics. Specification of cross-range capability provides the lift-to-drag ratio required by the orbiter and figures in the availability of a particular landing site during any given period. This availability is an important factor when satisfying an abort-from-orbit requirement.

The runway length required for safe landing at alternate landing sites is an important consideration for emergency conditions. The use of existing landing aids which should reduce DDT&E and operational costs, is important to the design of the on-board landing system, and should increase the number of acceptable landing sites.

Ascent Main Engine Failures. The system design will allow continuation of the nominal mission if an engine on both the booster and orbiter shut down safety during ascent. The performance margin will greatly enhance the crew, vehicle, and mission safety margin.

Common Propellants. The propulsion systems, main engine, OMS and RCS will use a common propellants. The AMLS propulsion system design and ground servicing operations will benefit from this groundrule.

Orbiter Airlock. The orbiter will have an airlock to allow shirt sleeve transfer of passengers to the Space Station and allow EVA into the payload bay. The combination of the airlock and hatches will always allow the transfer of all personnel to the crew module in an emergency situation.

EVA Provisions. The orbiter will contain provisions for two crew to go EVA and enough personnel rescue systems to allow transfer of the remaining crew and passengers through space to another vehicle.

Crew Work Area. This requirement sizes the interior of the crew module. Since all flight personnel will wear partial pressure suits during the ascent flight phase in case of cabin depressurization, it is necessary to allow sufficient space to accommodate them. The specification for 5 to 95 percentile personnel sizes has been derived from Space Station requirements and has been used previously in other manned vehicle design studies.

Manned/Cabin Atmosphere. This requirement addresses the need for the life support of the flight personnel. The capability to purge and repressurize will allow contingency repressurization and multiple on-orbit EVA's, if they should become a design requirement.

This will also provide cabin repressurization for a time criltical about in the case of a cabin leak.

2.2.3 AMLS Operations and Support Groundrules

The groundrules presented in Table 2-5 address the configuration of the ground operations and logistic support system the should be in place to support the program.

Table 2-5. AMLS Operations and Support Groundrules.

1. After becoming operational, the AMLS shall use aircraft-like techniques and methodologies where appropriate with a progressive program of scheduled hardware and software maintenance activities.
2. The AMLS spacecraft shall be designed for ease of access for maintenance and inspections.
3. System sensitivities to fluid consumables loading should be minimized. The number of different types of and use of highly toxic or corrosive fluids in the vehicle shall be minimized or eliminated. The use of pyrotechnics in all vehicle elements shall be minimized or eliminated.
4. There shall be adequate spares, with a probability of sufficiency of 0.95, to avoid cannibalizing. Initial orbiter and booster procurement shall accommodate attrition of either vehicle.
5. The cleanliness levels within the AMLS crew module shall comply with Space Station Environmental Requirements.
6. KSC is primary launch and landing site. Landing sites at other than the primary site shall exist for the purposes of flight safety and other contingencies.
7. The AMLS spacecraft shall be capable of being ferried by Land, Sea, and Air using existing commercial or government transport systems with minimum specialized GSE.

Efficient Operations. Advanced launch system operational approaches are required to ensure efficient and thus low cost AMLS operation. One such operational approach which offers promise is applying, where appropriate, methodologies and techniques from the airline industry to AMLS ground processing. With this approach, routine verification will be replaced by hardware and software performance trend analysis and monitoring.

Ease of Access. The subsystem design must support ease of access by the ground personnel that permit multiple maintenance technicians to work at one time. The design should also allow LRU removal without disturbing any other system element or interface. All inspection access requirements should be of a simple and reusable design and have a time limit established and verification performed to assure it was satisfied by the final design.

Minimal Fluid Servicing. Fluids that are not toxic or corrosive are favored for use, as well as single simple interface for servicing for each type of fluid. Also, the number of different fluids should be minimized to allow a small number of support equipment needed by the ground.

Adequate Spares. An important lesson learned from the Space Shuttle program is the importance of logistics, especially with regard to the timely adequacy of spares for all vehicle systems. By having adequate spares to avoid the necessity of cannibalizing another flight vehicle for replacement parts, the AMLS program can significantly reduce the chances of having "hanger queens" and can increase the chances of retaining a full fleet of operational and flight-ready vehicles.

Crew Area Cleanliness. As a consequence of the AMLS docking with the Space Station as defined in DRM-1, it is important that the orbiter comply with Space Station environmental requirements. This requirement affects prelaunch operations in terms of accessibility to the crew module and design of the crew access arm.

STS payload processing is accomplished in a Class-100,000 clean room. These clean room requirements will impact the PCS processing cost, both at the payload builder and integrator. This is due to additional cleanliness provision and procedures required in the processing buildings.

Launch and Landing Sites. The identification of launch sites determines the range of orbital inclinations, which directly affects launch vehicle performance requirements and orbiter injected weight, and is a significant factor in specifying logistic requirements. Landing of the vehicle at a site other than the launch site will require special logistic support to return the vehicle to the launch site.

Ferry Capability. Since the AMLS orbiter is the only reusable element of the AMLS system that will land at other runway sites, its ability to be ferried easily is an important factor to providing rapid turnaround capability. Ferry for both the booster and orbiter from the prime contractor should also be provided by the program. By specifying that existing transports are used with a minimum of specialized GSE, the AMLS vehicle turnaround time should be minimized. It also reduces the amount of AMLS-unique ground support required for turnaround operations, which again decreases operating costs.

2.2.4 AMLS Payload Containment System (PCS) Groundrules

The groundrules presented in Table 2-6 address the method in which payloads will be handled by the AMLS program.

Table 2-6. AMLS Payload Containment System Groundrules.

1. Modularized payload containment system (PCS) shall be used to facilitate off line processing of payloads. Customized PCS for alternate DRM's are desirable.
2. PCS shall allow for a high degree of payload manifesting capability. Numerous discrete attachment points shall be provided within the PCS for payload installations.
3. AMLS orbiter shall provide safety status monitoring of payload functions. This will include the ability to direct and relay telemetry and command with attached and released payloads. The PCS shall independently monitor the safety status of attached payloads and be able to shut down and make all payload systems safe.
4. Standardized power and environment levels shall be supplied payloads by the AMLS orbiter through a standardized interface concept to the PCS. Power and environment in excess of standard values shall be provided by and charged to the payload.
5. AMLS and PCS design shall allow for late payload access for minimal service at the launch pad, such as fluids, batteries, gases, and insertion of biological elements. Payload access at the pad will not be part of the nominal flow, but will be available as a payload option.

Payload Containment System. The mission payload will be integrated into the PCS off line. Thus the serial impact on the Orbiter and Booster processing will not be hindered by the payload requirements, except to mate and verify the PCS interfaces during preparation for booster/orbiter stacking.

PCS Flexibility. The design of the PCS should allow the ultimate of flexibility for the payload builder and the program to configure unique PCS's for rescue, on-orbit servicing, delivery, payload specific misssion, etc.

Monitoring and Statusing of Payloads. The PCS interface with the orbiter will allow safety monitoring of the status of the payloads in the PCS, as well as providing bent pipe communication of the payload with its ground system. The PCS shall incorporate the ability to safe all payloads automatically, independently, or with crew action.

Standardized Interfaces. The orbiter will provide a standard interface with the PCS, power, cooling, date, etc. The PCS will integrate the payloads to share this interface or use a dedicated portion. Any requirements for additional power or environmental control of the of the payload will be provided in the PCS for the payload as an optional service.

Access of Payload on The Pad. The AMLS orbiter/PCS will be designed to allow payload access in the horizontal and vertical. The late access by the Payload will not be considered a nominal operation, but will be made available under the right set of circumstances as a payload option and cost.

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3.0 HARDWARE/SOFTWARE DESIGN DESCRIPTION

This section documents the design and analysis work performed to initially select concepts for structures and TPS, mechanical systems, launch escape system, payload containment system, electrical power system, environmental control and life support system, MPS/OMS/RCS, and avionics areas. With the exception of the reliability and maintainability area, design concepts are proposed to support possible trade studies during the next phase of this contract. As such, these concepts represent a reasonable beginning point for further analysis.

3.1 GENERAL DESIGN FEATURES, AND MASS PROPERTIES

The general design features and the mass properties of major items in the orbiter and booster are described below. No major changes were made to the shape of the NASA LaRC-provided baseline configuration although each vehicle was photographically scaled to allow for needed structural depth between the inner and outer mold lines.

3.1.1 Orbiter

The major design features and overall dimensions of the AMLS orbiter are shown in Figure 3-1. It accommodates a crew of two and eight passengers in the forward crew compartment, which also serves as an escape module. The crew compartment is connected to the workstation by a pressurized tunnel. The workstation contains crew accommodations and an airlock for berthing to Space Station Freedom or access to the Payload Containment System (PCS). The PCS is detachable for payload integration and processing independent of the orbiter. The PCS usable internal dimensions are 30 ft. long by 15 ft. in diameter. The maximum payload weight is 40,000 lbs.

Integral LH_2 and LO_2 tanks with internal insulation, aluminum lithium walls and external metallic TPS comprise the majority of the body volume. Five modified SSMEs provide vertical takeoff ascent thrust. OMS/RCS uses integrated hydrogen/oxygen technology (IHOT) to provide on orbit/deorbit/descent maneuvering and control. The orbiter performs an unpowered reentry to a horizontal landing. Wing elevons and a body flap provide roill and pitch control while wing tip fins provide yaw control during the atmospheric stage of reentry.

The initial design of the orbiter placed the crew accommodations in the transfer tunnel. An evaluation of the concept revealed several problems with this approach which would hamper the crew and increase the difficulty of maintenance. The transfer tunnel has neither the size, shape, nor orientation to adequately meet the operational goals of the AMLS program; its cross-section area is not well suited for accepting both a passageway and required subsystems. Many existing NSTS components could be used on the AMLS but would have to be redesigned or repackaged to fit the smaller volume of the transfer tunnel. While all systems could be made to fit, the resulting passageway would be difficult to traverse. The passageway would be even less acceptable on the ground

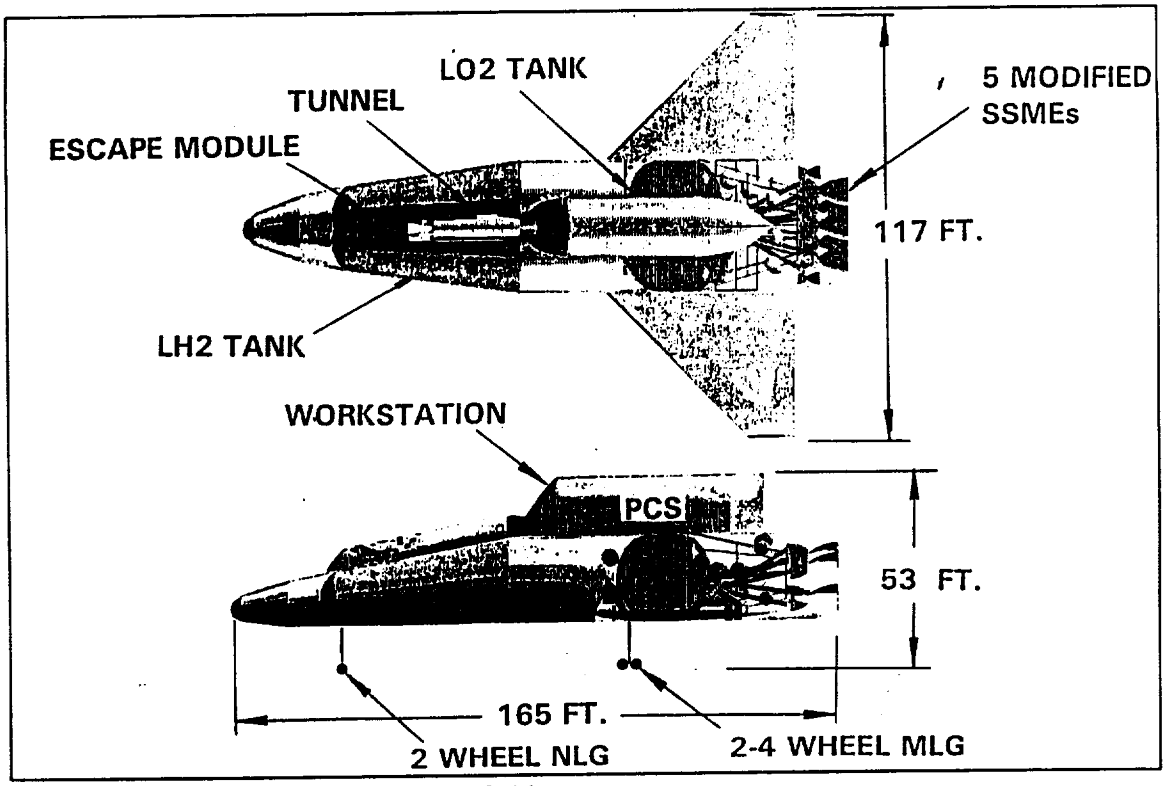


Figure 3-1. General Arrangement - Orbiter.

during servicing: workers would have to crawl through the tunnel which will be at an 11 degree angle. Also, no large tools or supplies could be brought inside.

A large workstation volume overcomes all of the problems encountered in the transfer tunnel. The large volume provides easy passage and ample room for storage and internal systems. The arrangement of floors and walls allows easier installation of existing Shuttle hardware. Also, the floors in the workstation are level and workers can stand erect during ground processing. All of these benefits simplify the ground processing of the system.

The workstation is designed to use as much of the forward PCS fairing volume as possible. The large workstation volume allows additional space to carry special cargo, store extra food, or simply provide more space to accommodate higher levels of activity. The workstation also accommodates an airlock which exits into the payload bay.

The shape of the workstation pressure shell will greatly impact its weight. If the workstation consists of a single irregularly-shaped module, maximum use of available volume is achieved. The drawback to this option is the module must be stronger (and therefore heavier) to react internal pressure forces. Reducing the cabin pressure by 4 psi to 6 psi while on-orbit would reduce this penalty. If the workstation is divided into multiple modules, cylindrical and conic modules could be used to efficiently (low weight) support the internal pressure. However, this approach does not effectively use the available volume, see Figure 3-2. A compromise solution has been selected which places sleep stations in the transfer tunnel and uses a structurally efficient single conic module for the workstation itself.

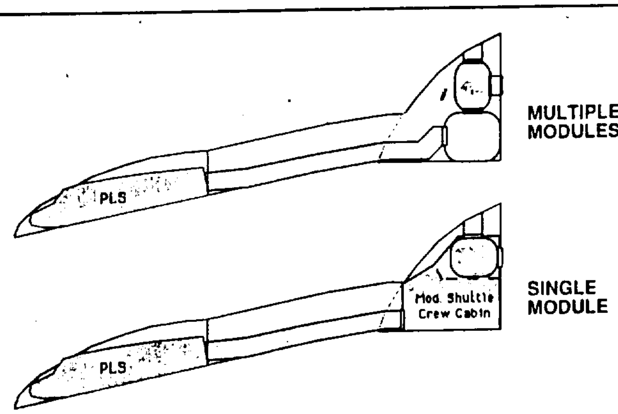


Figure 3-2. Various Workstation Designs are Viable.

By locating crew accommodations equipment in the aft flight deck area, the forward crew cabin size can be minimized to reduce the LES requirements. Some subsystems, consumables tankage, and sleep stations are located along the tunnel between the two areas, see Figure 3-3. The crew stowage, additional sleep stations, galley, waste management system, etc., are located in the larger aft volume.

Two options for SSF docking were considered. The first is the current STS in-bay berthing approach which requires a longer payload bay to allow room for the tunnel and airlock of the SSF-mating hardware. The alternate (and preferred) concept uses ASTP-type docking interface at the top of the aft flight deck under clamshell doors. This concept is believed to be less expensive, simpler and lighter. It is also compatible with Soyuz hardware. Since the current in-bay mechanism is the only one approved for current use at SSF, it was selected as the baseline approach.

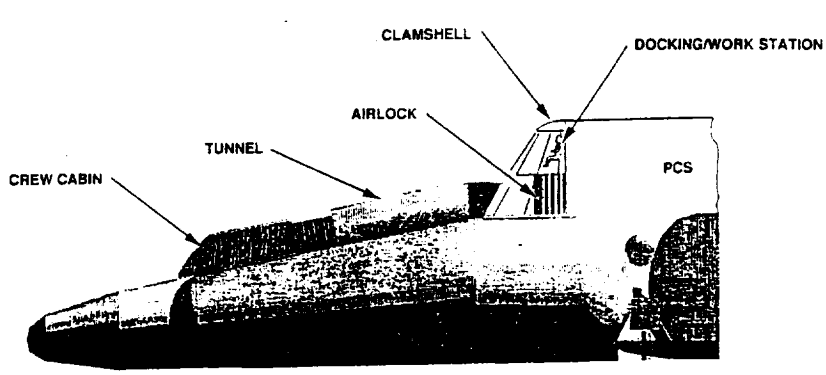


Figure 3-3. Crew Accommodations, Docking and PCS Control are provided in Aft Flight Deck.

3.1.2 Launch Escape System (LES)

A groundrule is to provide a crew escape capability over as wide a flight regime as possible. To achieve this, a Launch Escape System (LES) is designed into the forward crew module as shown in Figure 3-4. The system is available for use from the launch pad through Mach 6 on ascent. (It is assumed that the vehicle will abort intact during the descent flight phase.)

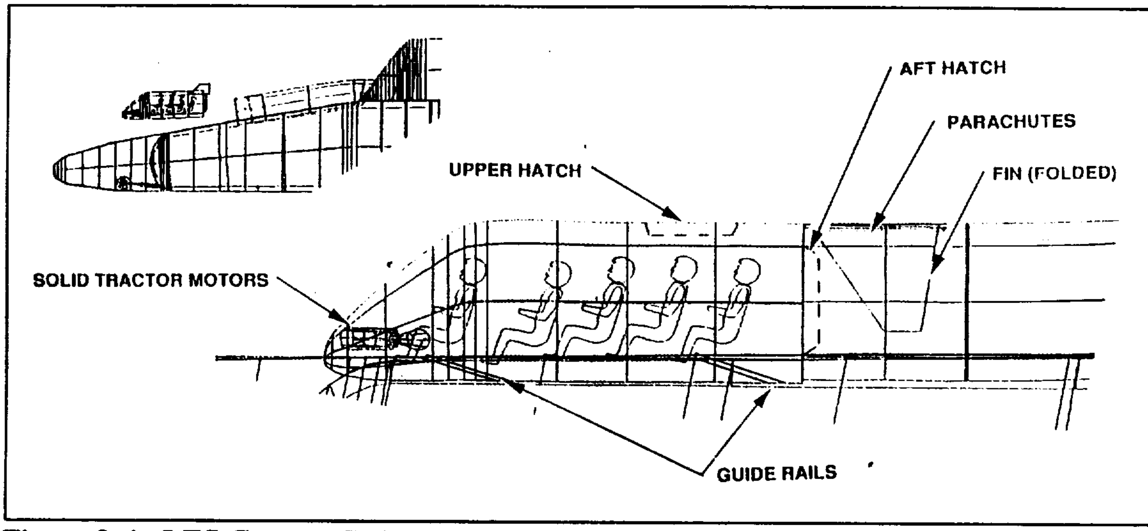


Figure 3-4. LES Concept Enhances Crew Safety During Ascent.

The LES vehicle is the forward crew cabin in which all ten personnel are seated during all non-coast flight phases. The crew cabin is a cylindrical pressure vessel with an aerodynamic nose cone. Separation from the tunnel occurs immediately aft of the aft hatch in the crew cabin. The aft fairing structure which houses the parachutes and flotation system also provides some aft aerodynamic surface area. To achieve passive aerodynamic stability, a pair of trapezoidal fins are automatically deployed at LES initiation.

Acceleration is provided by a pair of 1400-pound solid rocket motors installed in a thrust structure in the nose of the LES vehicle. Using this tractor arrangement simplifies the rocket control system by eliminating a complex TVC system and by reducing the installation alignment requirements for the motors. The initial separation from the orbiter is controlled by means of short guide rails.

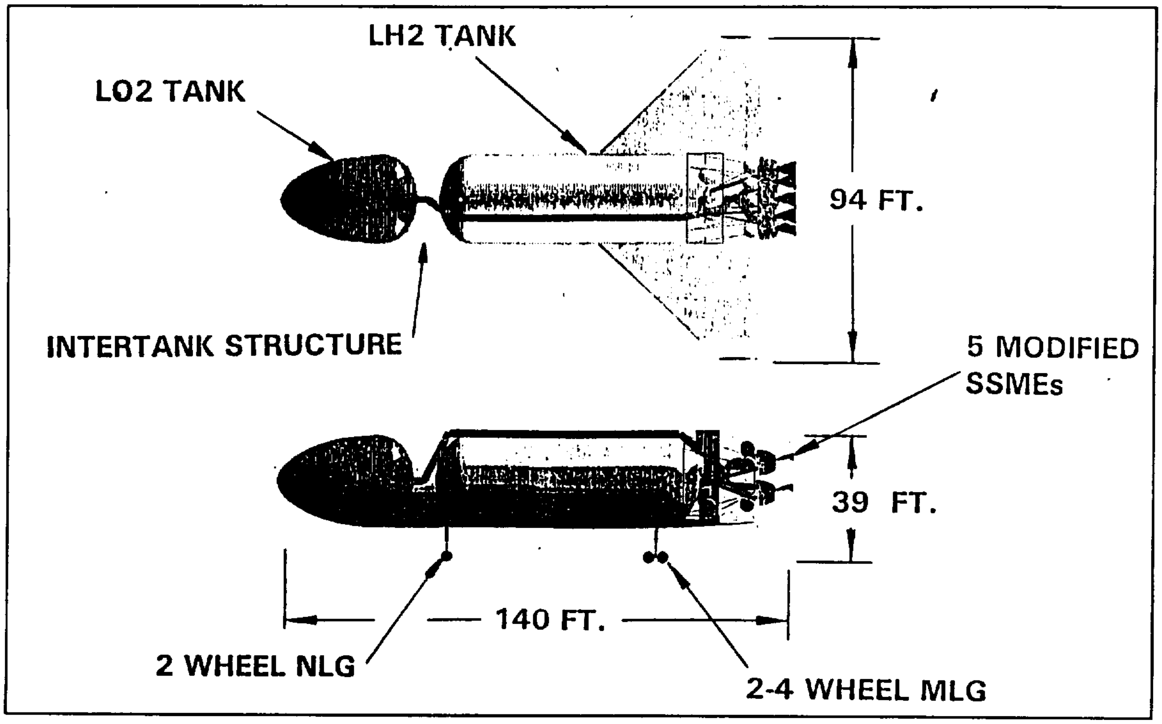


Figure 3-5. Booster General Arrangement.

3.1.3 Booster

The booster is an unmanned, fully reusable vehicle. Major design features and overall dimensions of the AMLS booster are shown in Figure 3-5. Integral LO_2 and LH_2 tanks with external insulation and aluminum-lithium walls comprise the majority of the body volume. Five modified SSMEs provide vertical takeoff ascent thrust up to staging at Mach 3. A reaction control system (RCS), employing integrated hydrogen/oxygen technology, provides control authority during the booster's unpowered return to the launch site, and lands horizontally. Wing elevons and a bodyflap provide roll and pitch control, while wing tip fins provide yaw control during the return to the launch site.

3.1.4 Mated Configuration

The orbiter is mated to the top of the booster while the vehicles are in a horizontal position. The orbiter's weight is transferred via external structs to the ground transporter which also supports the booster. The ground transporter also acts as a strongback for erecting the vehicles to a vertical position at the launch pad. At the pad, the number of umbilicals are minimized to reduce on-pad operations. Since the booster crossfeeds propellant to the orbiter this same connection is used to load the orbiter propellant tanks, thereby reducing the number of pad-to-vehicle fluid interfaces. Rise-off disconnects will also be used to reduce pad operations. A minimal tower will be provided for crew ingress/egress and minor payload access. All venting will be through pad interfaces. Figure 3-6 shows the mated configuration on the launch pad.

3.1.5 Mass Properties

AMLS parametric weight estimating relationships have been developed, critiqued and revised such that the weight data represents the construction, materials, systems, and configuration of the orbiter and booster vehicle illustrated in this report. The template used to complete and present the resulting weight and longitudinal centers of gravity is the LaRC program CONSIZ. The data are presented in Tables 3-1 and 3-2 for the orbiter and booster vehicles.

Orbiter. The exposed wing and tip fins have almost the same wing loading as the STS orbiter (117psf vs. 119 psf) but is constructed of a high temperature capable metal matrix composite (titanium aluminide) which obviates the need for upper surface thermal protection. The structural unit weight is almost the same as the STS orbiter but the average unit weight including the lower surface carbide TPS panels is 20% less than the STS orbiter using aluminum- silicon tile TPS system.

The sides of the aluminum lithium (Al-Li) LH2 tank support the flight loads between the organic composite (Gr/PEEK,Gr/Polyimid) nose and aft body. Aerodynamic panels are also provided to cover the upper and lower tank open lobe areas. The Al-Li tank weight is 15% less than the comparable STS ET aluminum tank but 15% was added for stiffening and internal lobe tension ties, for an essentially unchanged unit weight.

The use of organic composites for the remaining body sections reduced the unit weight by 25% from the STS type aluminum structure. The lobed conical thrust

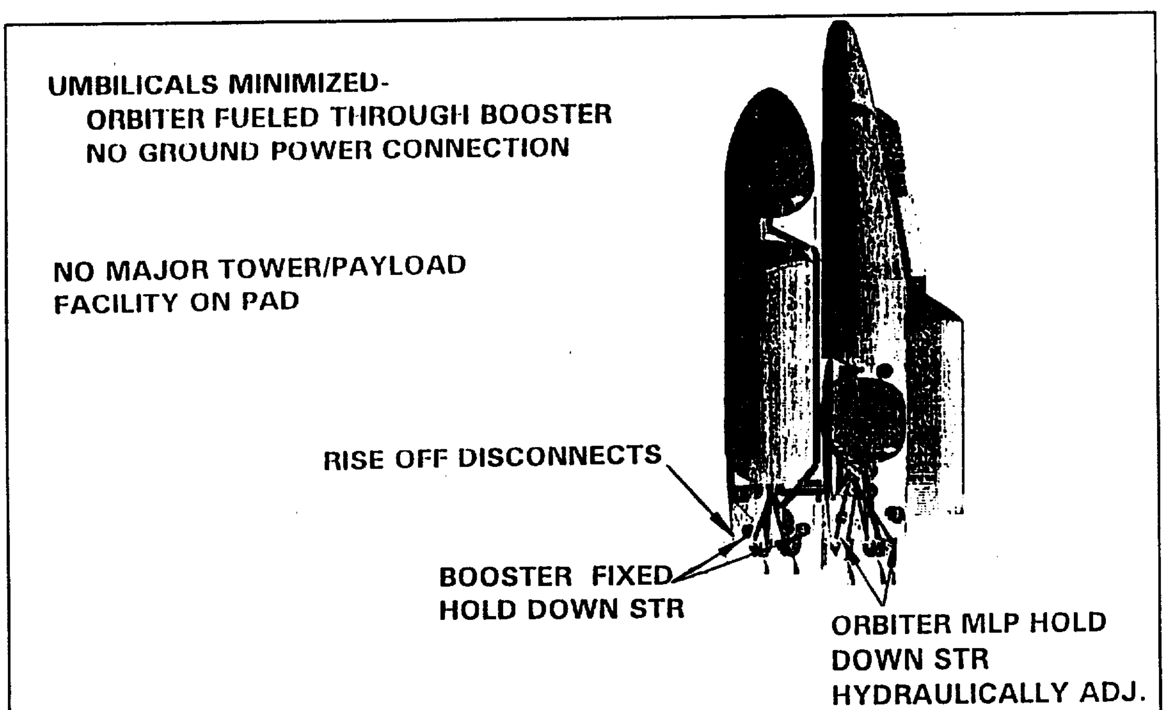


Figure 3-6. Mated Vehicle Configuration.

structure was assumed to have a unit weight (weight-to-thrust) ratio similar to the STS orbiter thrust structure.

The crew cabin was sized to hold two pilots and eight passengers for three days and the equipment necessary to support the crew during an emergency escape rocket sequence. See the crew escape capsule paragraph. The weight of the payload shroud, access tunnel, and tunnel fairing were taken from LaRC data.

The thermal protection system utilizes advanced carbon-carbon (ACC) for the nose and wing leading edges and carbon/silicon carbide panels on the lower body and wing surfaces, three dimensional silicon fabric with Q-filer filled blankets (AFRSI or TABI) on the sides and on top of the organic composite body structure. No protection is required on the MMC wing upper surface.

Sealed multi-layer insulation (MLI) is installed inside the LO_2 and LH_2 tanks at an average unit weight of 0.65 psf. The weight of the helium purge tank is based on the STS He tanks and is 6 times the He contents weight for a titanium lined-Kevlar wrapped high pressure tank. The internal thermal control system employs equipment cold plates, a coolant loop, body mounted radiators and bulk insulation blankets to protect the avionics and control equipment. The weight is estimated as a percentage of the avionics equipment weight and a factor of the unpressurized body volume.

The nose and main landing gear were taken from the B-767 aircraft which has about the same landing weight. The total weight is 3.6% of the landed weight. The escape and recovery items belong to the crew escape capsule system which is discussed below.

The main propulsion engine weight is based on the SSME. The system components are based on the STS orbiter and ET systems. However, the STS hydraulic TVC actuators are replaced with an equivalent electro-mechanical actuator and the heat shield is made of protected GR/EP rather than the steel system of the STS orbiter. The RCS and OMS systems use the Integrated Hydrogen/Oxygen Technology study (Reference 3-1), system which employs a gaseous H2/02 RCS and pressure fed H2/02 OMS.

The electrical power generation system employs high-density fuel cells and a LO_2/LH_2 cryo tank system to supply the equipment power and a small battery to initiate the escape capsule seperation and provide power during descent.

The aerodynamic surface actuators are electro-mechanical (as also are the main engine TVC actuators). The unit weight was assumed to be the same as the STS orbiter hydraulic actuators.

The avionics weight data was taken from the personnel launch system (PLS) data (Ref.erence 3-2) and is about 25% of the STS orbiter system weight.

The LaRC parametric data for the environmental control system and the personnel provisions were used unchanged.

The inert weight is the sum of all the above elements plus a 15% growth contingency factor applied to all elements except the payload shroud and the fixed landing gear weight.

The LaRC parametric data for the personnel residuals, reserves, OMS and RCS propellants and payload was also used directly. The only "useful load" elements modified were the subsystem residudal fluids which now include fuel cell reactants and retained purge helium. The in-flight losses now include only consumed fuel cell reactants and cooling water.

Crew Escape Capsule. This system is designed to contain 10 crew and land them safely after an emergency escape from a faulty launch vehicle. The capsule is composed of structure, TPS and the system elements that are installed inside the capsule and cannot be left behind. Figure 3-4 illustrates the component elements, the recovery parachute system, and the escape rocket system. All of these elements are included in the orbiter weight data and are deliniated here for reference only.

Booster. The small value of the staging velocity and the light wing loading leads to the selection of a heat-sink type vehicle, in which the return heat is absorbed by the vehicle and little external insulation is required.

The exposed wing (including the tip fins) have almost the same area as the STS obiter. The wing loading, however, is about 33% less (80 psf vs 119 psf). The titanium leading edges and the graphite polyimid acreage construction and the reduced wing loading resuts in a 40% lighter unit weight than the STS orbiter aluminum construction system.

The body is primarily constructed of sections of the LO_2 and LH_2 Al-Li tanks. The shape and construction are similar to the STS ET. The Al-Li reduces the unit weight by 15% but an additonal 15% was added to provide additional stiffness and reuseability for a net constant unit weight. The Al-li intertank structure and Gr/Pi aft engine compartment structure result in an average unit weight about 17.5% less than the STS orbiter. The lobed conical thrust structure was assumed to have a unit weight ratio similar to the orbiter vehicle and the STS orbiter.

External TPS consists only of spray-on-foams (SOFI) insulation at a unit weight of 0.25 psf on the external tank surfaces to provide no ice build-up during ground hold. The internal thermal control system is a passive bulk insulation blanket system (ie, TG-5000) to protect the avionics and control equipment.

For cost containment purposes, the booster will use the same landing gear as the orbiter, even though the booster is 1/2 the orbiter weight at landing. This results in a gear weight/landed weight percentage of 7.1%.

The main propulsion system of the booster is almost the same as that of the orbiter. The main difference is the use of a low expansion ratio nozzle. 'This reduces the weight and increases the sea level performance.

The RCS system is virtually the same as the orbiter system. No OMS system is required on the booster.

The booster also utilizes a high density fuel cell system and cryotank system to provide electrical power. The fuel cell weight is presented in the line titled "batteries, SC and gimbles", and the reactant dewars in the line titled "batteries avionics".

Since the booster vehicle is about half the orbiter size, the electrical power distribution and control and the aerosurface actuation system is also about half the orbiter system weight.

The avionics system is an unmanned autonomous system that is very similar to that of the orbiter with the display and control system for the crew removed.

The environmental control system needs only to control the heat load of electrical and avionics equipment for a short time and the weight is about 12.5% of the orbiter system weight.

The LaRC 15% growth margin was retained as reasonable, for a vehicle at this level of description. As in the orbiter, the LaRC parametric data for the residuals, reserves, and RCS propellant were used directly. The residuals now include only fuel cell reactants and retained cooling water. The infight losses include only the consumed reactants and cooling water.

In comparison to the orbiter, the booster entry weight is 51%, the ascent propellant 83%, and the gross weight 76%. The mass fraction (propellant/(inert and propellant)) is 0.874 for the booster and 0.814 for the orbiter. The booster is then 37% more efficient than the orbiter, or put the other way around, the penality of crew, payload, and a high entry velocity is 58% more than a vehicle without those requirements.

3.2 STRUCTURES AND TPS

The AMLS structural design was developed to identify basic requirements and concepts. Structural concepts and materials were selected based on experience in aircraft and spacecraft system design and operation, as well as on results of recent studies and programs such as NASP, SSTO and PLS. The basic objective of this study was to identify and recommend baseline concepts that promise high vehicle and system performance at low development and operational risk.

The approach was to select design concepts and materials that are known to provide efficient, reliable structures. In general, conventional materials are used, but some advanced materials that are expected to be developed and certified in the next few years are also indicated.

The LaRC baseline design was reviewed and a few material changes suggested to enhance operability or producibility. A major point of internal discussion revolved about the use of materials and construction processes not in common commercial use today versus the stated program objective of stressing the importance of operability and maintainability. The materials and processes chosen represent those which Rockwell believes will result in the best possible compromise between increased operability, structural efficiency, temperature capability, and required payload to orbit performance given a technology maturation date of 2000. Structural materials have been selected from the list in Table 3-1 to correspond with the maximum reuse temperatures shown Some of the materials and concepts were selected because of their expected development in other programs, such as NASP, in time to support the AMLS schedule. Should some of the recommended materials and processes not mature adequately, and this program alone can't be responsible for their maturation, then alternates have been identified with some impact on payload performance. Material and process choices may also change during the next phase, particularly for the orbiter, as the temperature profiles are refined to reflect more than only the vehicle centerline and wing leading edges. Detailed structural analysis being performed by NASA LaRC is also expected to result in revisions to the proposed structural concepts.

The basic requirements for the AMLS structure are integrity, durability, maintainability, fabricability, light weight, long life, and the design factor of safety. Each of these items is discussed in the following paragraphs:

- Structural integrity and durability are of primary concern. The structure must be capable of supporting all design loads and thermal conditions for the design lifetime while maintaining the required factors of safety.

- Maintainability must be built in to the structural design. This includes accessibility for inspection and repair, and structural concepts and materials that can be efficiently and effectively repaired with minimal impact to operations.

- Fabricability affects initial costs. Materials and structural concepts must consider the ease and cost of fabrication. Accessibility for assembly and inspection must be provided.

- Minimizing dry weight is important, but is of lower priority compared with the previously mentioned subjects. Long life must be built into the structure by selecting of operating stress levels to minimize fatigue effects, and in providing durable structures that are not easily damaged by operational conditions or inadvertent impacts or minor accidents.

Table 3-1. Structural Materials.

STRUCTURAL MATERIALS		INSULATION MATERIALS	
* 2090 ALUMINUM-LITHIUM	350° F	* SOFI	300° F
* TITANIUM ALUMINIDE	1300	ROHACELL FOAM	400
1100 TITANIUM	1100	KAPTON/AL FILM	350
GRAPHITE EPOXY	350		
GRAPHITE PEEK	400		
GRAPHITE BISMALEIMIDE	450		
* GRAPHITE POLYIMIDE	550		
		HEAT SHIELD MATERIALS	
		* AFRSI	1500° F
		TABI	1800
		ACC	2700
* SELECTED MATERIALS		* C/SiC	2800

- A design factor of safety of 1.5 is used to provide for occasional overloads, for degradation in structural properties over the lifetime of the system, for minor design analysis inaccuracies, for minor accidental damage, and for other unforeseen occurrences which may degrade the structure. A factor of 1.5 is commonly used for military and commercial aircraft.

3.2.1 Booster

As shown in Figure 3-7, the booster structure consists of two propellant tanks, an intertank structure, a nose cap, aft structure that incorporates wing carry-through, thrust structure interface, orbiter attachments, a wing and wing tip fins, landing gear supports, insulation, and internal equipment supports.

Both propellant tanks are constructed of welded aluminum-lithium alloy. The intertank structure is also made of aluminum-lithium alloy, for thermal compatibility with the tanks. The wing is primarily graphite polyimide composite construction, while the wing and tip fin leading edges and body nose cap are titanium, to withstand heating and impact at these locations. The thrust structure is made of an aluminum-based composite material to provide extra strength and stiffness. Removable non-structural graphite composite panels cover the aft section to provide easy access to internal subsystems.

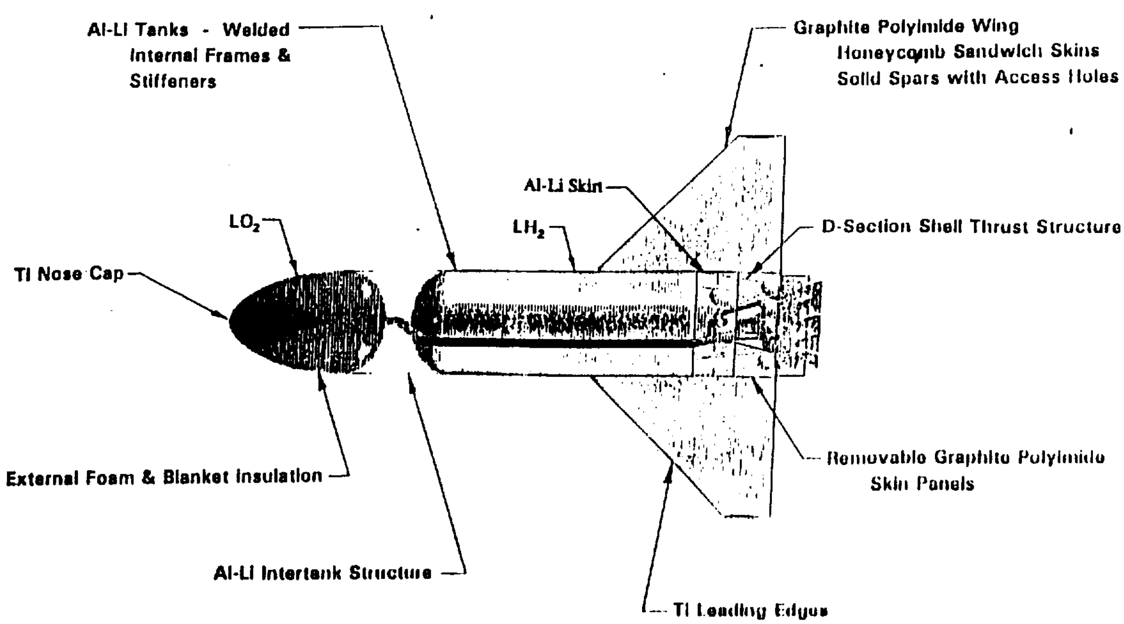


Figure 3-7. Booster Structure.

Booster design load factors were derived from study ground rules and are listed in Table 3-2. Ascent load factors are the same for the booster and orbiter. Descent and landing conditions were assumed to be the same as for the orbiter. Thrust values used are for the SSME-derived engines as described in the NASA Baseline Vehicle Description. Approximate temperature values were obtained from NASA thermal analysis runs. These temperatures were used only to establish the suitability of proposed material applications.

The booster propellant tanks, shown in Figure 3-8, are welded aluminum-lithium alloy construction. Weldalite, 2090 and 8090 alloys are all weldable and are candidate alloys. Basic construction is similar to the Shuttle external tank, with internal frames and longitudinal stiffeners. The LO_2 tank contains slosh baffles, which are mechanically attached to internal structural frames. The welded tank structure includes aluminum-lithium attachment skirts, which provide thermal strain isolation from adjacent warmer structures.

Table 3-2. Booster Loads and Criteria.

ULTIMATE DESIGN LOAD FACTORS		
ASCENT	DESCENT	LANDING
N_x = 4.5	N_x = 0.75	N_x = 1.5
N_y = 0.7	N_y = 1.5	N_y = 0.75
N_z = 1.05	N_z = 3.75	N_z = 3.75
THRUST		
SEA LEVEL THRUST = 2,270,000 LB		
ALTITUDE THRUST = 2,485,000 LB		
TEMPERATURES		
ASCENT - NOSE TEMPERATURE = 500° F		
DESCENT - WING LEADING EDGE TEMP = 500° F		
0.2 AFT ON BODY TEMP = 400° F		

A spray-on foam external insulation, similar to that used on the Shuttle external tank, is proposed for the AMLS booster. This type of

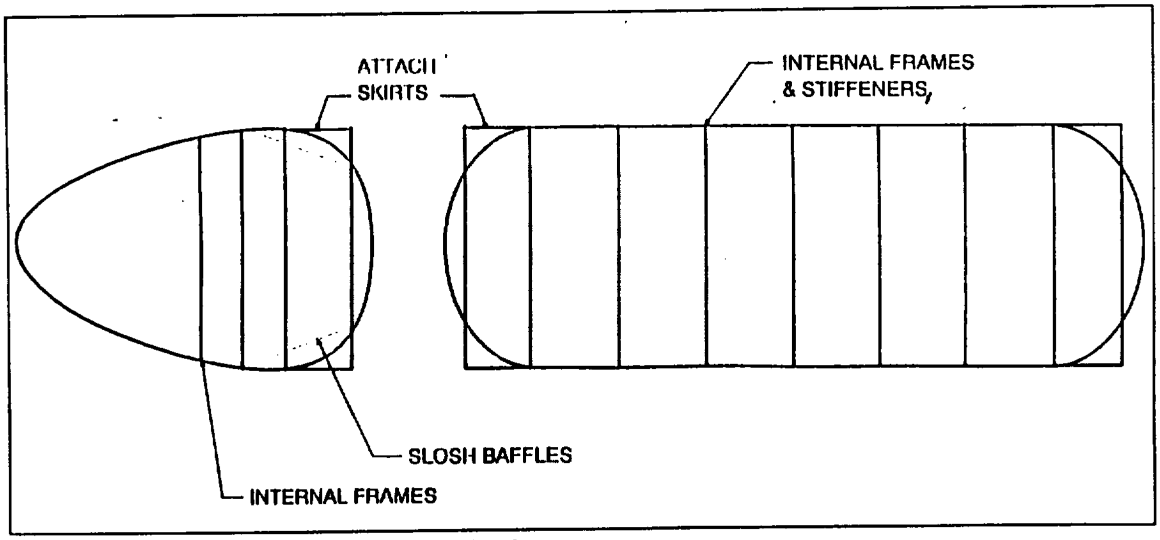


Figure 3-8. Booster LO2 and LH2 Tanks.

insulation is easily applied, inspected and repaired. Its durability in repeated use must be established. Repeated filling of external tanks in Shuttle operations has not caused extensive cracking of the insulation, although this also remains an item of concern which will require further study. The external foam insulation may also provide thermal protection for the tank structures, where it is required.

An alternate concept for cryogenic insulation has been under way at NASA LaRC for several years. This concept employs internal closed-cell foam blocks which are bonded to the interior of the tanks. The foam blocks are wrapped in an impervious film wrapper such as aluminized kapton which facilitates sealing of the cracks between blocks and minimizes seepage of hydrogen gas into the foam. This concept has the advantages of leaving the external metal surface of the tank accessible for inspection, except in areas where thermal protection is used, and of minimizing the thermal stresses in the metal tank structure that are associated with large temperature excursions.

The intertank structure is attached directly to the aluminum-lithium tank structure, and is fabricated from aluminum-lithium in order to minimize thermal strain differences. The intertank structure includes internal frames and longitudinal stiffeners, which are mechanically attached to the shell. The intertank includes two large access doors which are used for access to the interior and for inspection of the tanks. Hard points will be provided for attaching the inspection GSE and work platforms in order to facilitate maintenance operations. The intertank structure also houses the nose landing gear of the booster and supports the forward orbiter interface link.

The thrust structure supports the five booster engines on a D-shaped conical shell. The conical shell transmits thrust loads efficiently to the outer tank shell. Aluminum-silicon carbide, an advanced metal matrix composite material is proposed to provide extra stiffness and strength to the thrust structure. Longitudinal stiffeners are mechanically attached to the conical shell. An aluminum ring at the aft end provides a standard interface for engines, feed line supports and actuators. The aft ring also supports the aft heat shield. An aluminum ring at the forward end interfaces with the booster aft structure.

The aft structure provides the connection between the thrust structure and the LH_2 tank. It also includes the wing carry-through structure, which must be designed to allow the thrust structure to pass through it, and ties the wing to the body. The upper part of the aft structure includes the orbiter interface fittings. This is a very heavily-loaded structure, with loads and stresses in all directions. It is constructed of aluminum-lithium alloy, with some aluminum-based metal matrix materials used in heavily-loaded members. The wing carry-through structure is graphite polyimide, which is mechanically attached to the aluminum-lithium frames and shell structure. The body flap is also supported from this structure.

The aft portion of the vehicle, surrounding the thrust structure and propulsion system, is made up primarily of removable non-structural panels. These panels are supported from the aft primary structural frame and the aft heat shield, which is mounted off the thrust structure. The non-structural panels are constructed of lightweight graphite polyimide honeycomb sandwich, designed to resist aerodynamic and acoustic loads and to transmit them to the supporting structural members. Edge seals, similar to the design used on the Shuttle payload bay doors, will be used. No external TPS is required.

The booster wing is a graphite polyimide box beam with three spars, as shown in Figure 3-9. The skins are honeycomb sandwich panels, mechanically attached to the internal structure. The spars are solid laminates, with stiffeners co-cured with the spar web to provide a reliable monolithic structural panel. The ribs are open truss-plates made of graphite polyimide laminates to provide an efficient load path while allowing accessibility for inspection and maintenance. Accessibility is provided through access doors in the upper surface structural panels.

The forward spar is attached to the LH_2 tank wall by vertical links. These links take lift loads but permit the LH_2 tank to expand and contract without transmitting longitudinal loads into the wing or tank. A root rib carries the drag load back to the rigid attachment at the aft structure.

The wing tip fin construction and materials are similar to those used in the wing structure. Control surface actuators are located aft of the rear spar for accessibility. Movable control surfaces may be constructed of graphite bismaleimide if the 450 F temperature limit of this material can be assured. Graphite

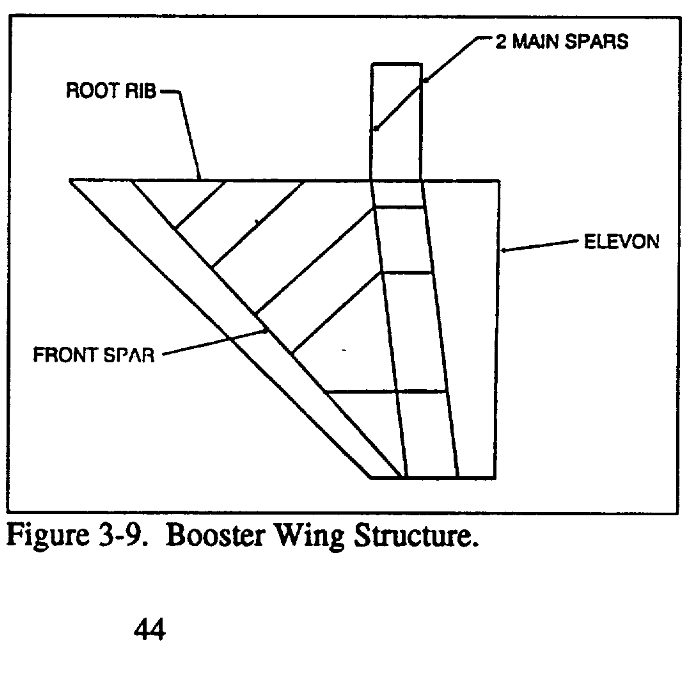


Figure 3-9. Booster Wing Structure.

bismaleimide is easier to fabricate than graphite polyimide and will be proposed for use throughout the structure where design temperatures permit. Full depth honeycomb is used in thin composite trailing edge locations.

Predicted temperatures on the booster are 500 F or below, so that little thermal protection will be required. The nose cap, at the forward end of the LO_2 tank, is a titanium conical shell, which is resistant to bird and ice impact and will protect the tank material from temperatures over 350 F during descent.

Temperatures on the external foam insulation may exceed its capability in limited areas, and may be protected with an emissivity coating or ablator, as is done on the Shuttle external tank. If an ablator is required, a material will be selected that can be reused for several flights before refurbishment. This may require some material development work to identify and evaluate candidate materials. If internal cryogenic insulation is used, an external emissivity coating may be required to maintain aluminum tank structural temperatures below 350 F during descent flight.

The graphite polyimide wing and tip fin structures will withstand extended service at 500 F and require no external thermal protection.

3.2.2 Orbiter

The orbiter structure consists of two propellant tanks, an intertank structure, forward structure, a nose cap, aft structure that incorporates wing carry-through, thrust structure interface, and orbiter attachments, a wing and wing tip fins, landing gear supports, insulation, and internal equipment supports, as shown in Figure 3-10.

Both propellant tanks are of 2-lobe design with a central web, and are constructed

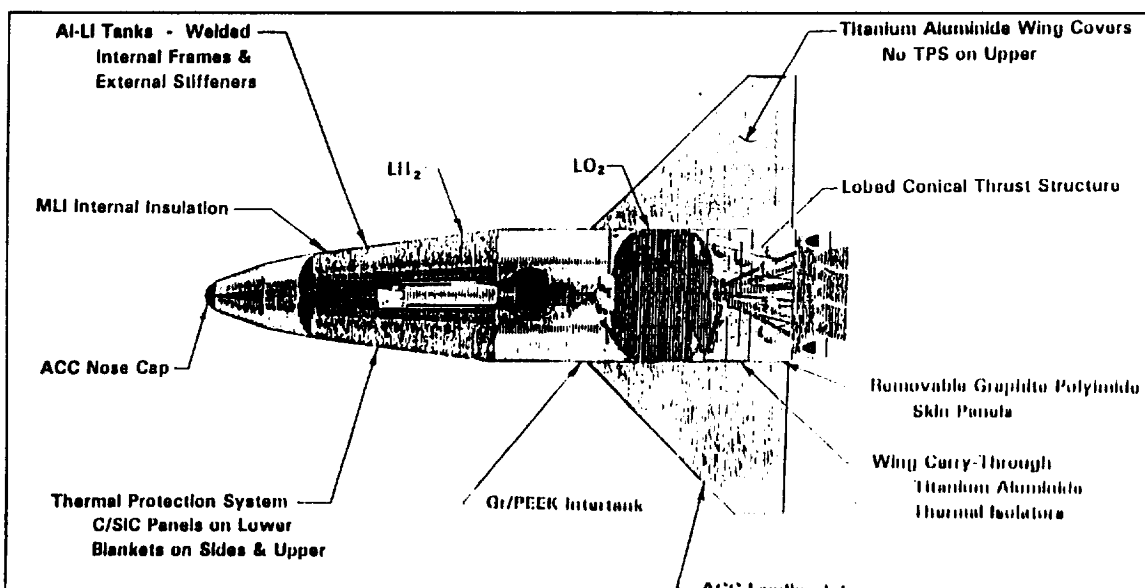


Figure 3-10 Orbiter Structure.

of welded aluminum-lithium alloy. The intertank structure is made of graphite-reinforced thermoplastic. The wing is stiffened titanium aluminide construction, while the wing and tip fin leading edges and body nose cap are ACC to withstand heating and impact at these locations. The thrust structure is made of an aluminum-based composite material to provide extra strength and stiffness. Removable non-structural graphite composite panels cover the aft section to provide easy access to internal subsystems.

Durable, hard surface thermal protection tiles are mechanically attached to the lower portion of the tanks and wing. Upper surfaces, where temperatures are below 1800 F, are protected by flexible ceramic insulation blankets which are bonded to the structure.

Orbiter load factors, presented in Table 3-3, were derived from AMLS study ground rules. Ascent load factors are the same for the booster and orbiter. Descent and landing conditions apply to the orbiter with propellant tanks empty. Thrust values used are for the SSME-derived engines as described in the NASA Baseline Vehicle Description. Approximate temperature values were obtained from NASA thermal analysis runs. These temperatures were used only to establish the suitability of proposed material applications.

Table 3-3 Orbiter Loads and Criteria.

ACCELERATIONS		
ASCENT	DESCENT	LANDING
$N_x = 4.5$	$N_x = 0.75$	$N_x = 1.5$
$N_y = 0.7$	$N_y = 1.5$	$N_y = 0.75$
$N_z = 1.05$	$N_z = 3.75$	$N_z = 3.75$
THRUST		
SEA LEVEL THRUST = 2,092,500 LB		
ALTITUDE THRUST = 2,567,500 LB		
TEMPERATURES		
ASCENT - NOSE TEMPERATURE = 1000° F		
DESCENT - WING LEADING EDGE TEMP = 2800° F		
0.2 AFT ON BODY TEMP = 1800° F		
WING UPPER SURFACE TEMP = 1000° F		

The orbiter propellant tanks, shown in Figure 3-11, are welded aluminum-lithium alloy construction. Weldalite, 2090 and 8090 alloys are all weldable and are candidate alloys. Both tanks are a 2-lobe design with a central web. Tank ends are modified ellipsoidal shells, that also attach to the central web. Welded attachment skirts provide thermal strain isolation from adjacent structures.

The tanks have internal frames for structural stability. Major frames at the ends, at the beginning of the tapered section of the LH_2 tank and at external loading points, distribute loads into the tank shell primary structure. The central web is a plate-girder construction, with openings for propellant passage and for maintenance access. The web is mechanically attached to the welded shell. An extruded or machined y-section longeron is used at the joint between the shell and the web, and helps to introduce thrust loads into the tanks. External stiffeners are used on the lower part of the LH_2 tank, for attachment of the thermal protection panels. On the upper part, which uses bonded-on blankets, the stiffeners are on the inside of the tank. Since the tank is made in sections and has a large radius stiffener location should pose no manufacturability concern.

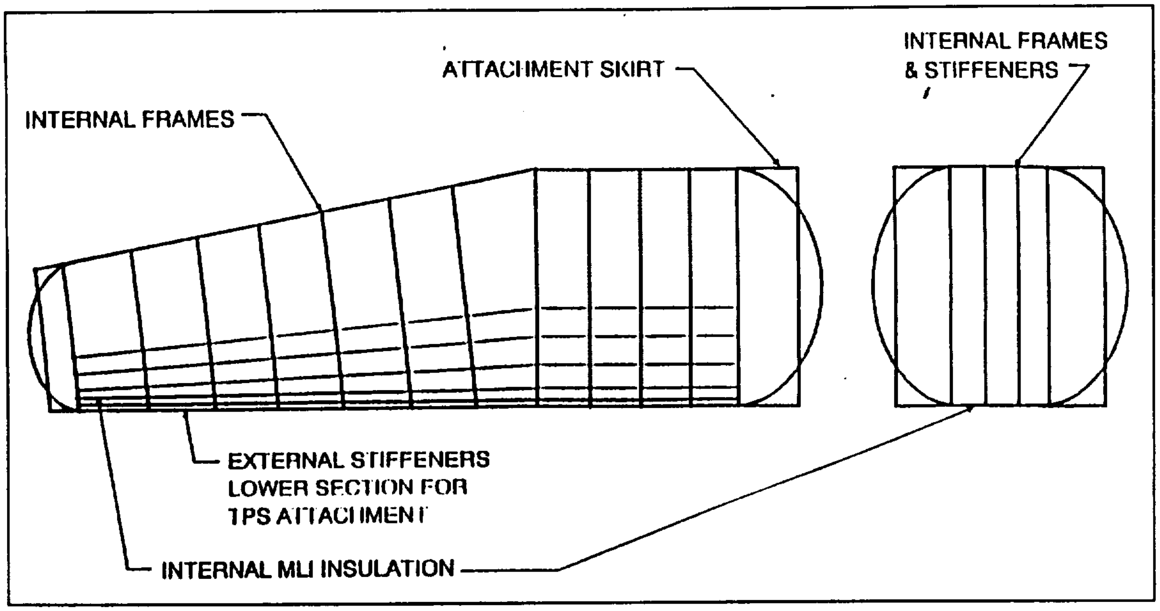


Figure 3-11. Orbiter Propellant Tanks.

Internal multilayer insulation (MLI) is proposed for use in the orbiter. Using internal insulation separates the functions of cryogenic insulation and TPS and allows each to be designed and maintained separately. MLI was developed by Linde Corp. for the Rockwell NASP design. This evacuated insulation is thermally efficient and takes up little tank volume. MLI panels are bonded to the structure between frames and stiffeners, and the joints are sealed using a thermoplastic or similar tape, which can be applied with a heat gun or laser. MLI is not appropriate for insulating internal frames and stiffeners. Formed foam blocks have been used in the Shuttle aft fuselage for insulating cryogenic feed lines and could be used for covering tank frames and stiffeners. The blocks would be wrapped in an aluminized kapton impervious wrapper to prevent propellant migration into the insulation. Additional development is required to validate this concept.

The forward structure contains the forward RCS system, the nose landing gear and supports the ACC nose cap. The nose cap is similar to the Shuttle orbiter nose cap. This concept provides thermal protection and impact resistance from birds, ice, and rain. The orbiter intertank structure joins the LH_2 and LO_2 tanks and supports the weight of the LH_2 tank on the launch pad. This structure also includes the wing forward spar beam, the upper payload carrier interface, and two large access doors for tank maintenance. Both structures are made of graphite-reinforced PEEK thermoplastic, with graphite PEEK internal frames, which are mechanically attached to the shell. Graphite PEEK longitudinal stiffeners are bonded to the shell using secondary bonding. In the lower portion of the structure, the stiffeners are external for attachment of thermal protection panels. Because of the elevated temperature capability of the PEEK resin (about 400F), reduced TPS thickness is possible in this area. Graphite PEEK is used for the intertank on the orbiter because of its light weight and because the internal insulation on the orbiter provides a warm tank surface for attachment.

The aft structure provides the connection between the thrust structure and the LO_2 tank. It also includes the wing carry-through structure and ties the wing to the body. The lower part of the aft structure includes the booster interface fittings. The upper part of the aft structure supports the payload carrier. This is a very heavily-loaded structure, with loads and stresses in all directions. It is constructed of aluminum-lithium alloy, with some aluminum-based metal matrix materials used in heavily-loaded members. The wing carry-through structure is titanium aluminide, which is mechanically attached to the aluminum-lithium frames and shell structure. The body flap is also supported from this structure.

The lobed conical thrust structure supports the horizontal engine arrangement, three above and two below, and matches the shape of the LO_2 tank, see Figure 3-12. The conical shell transmits thrust loads efficiently to the outer tank shell, directly aft of the heavy LO_2 tank. Aluminum silicon carbide, advanced metal matrix composite, is proposed in this application to provide extra stiffness and strength to the thrust structure. Longitudinal stiffeners are mechanically attached to the conical shell. Tapered longerons at the upper and lower center lines provide concentrated support for the center of the LO_2 tank. An aluminum ring at the aft end provides a standard interface for engines, feed line supports and actuators. The aft ring also supports the aft heat shield. An aluminum ring at the forward end interfaces with the orbiter aft structure.

The aft portion of the vehicle, surrounding the thrust structure and propulsion system, is made up primarily of removable non-structural panels. These panels are supported from the aft primary structural frame and the aft heat shield, which, in turn, is mounted off the thrust structure. The non-structural panels are constructed of lightweight graphite polyimide honeycomb sandwich, designed to resist aerodynamic and acoustic loads and to transmit them to the supporting structural members. The panels and surrounding structure are covered with AFRSI thermal protection blankets. Edge seals, similar to the design used on the Shuttle payload bay doors, will be used.

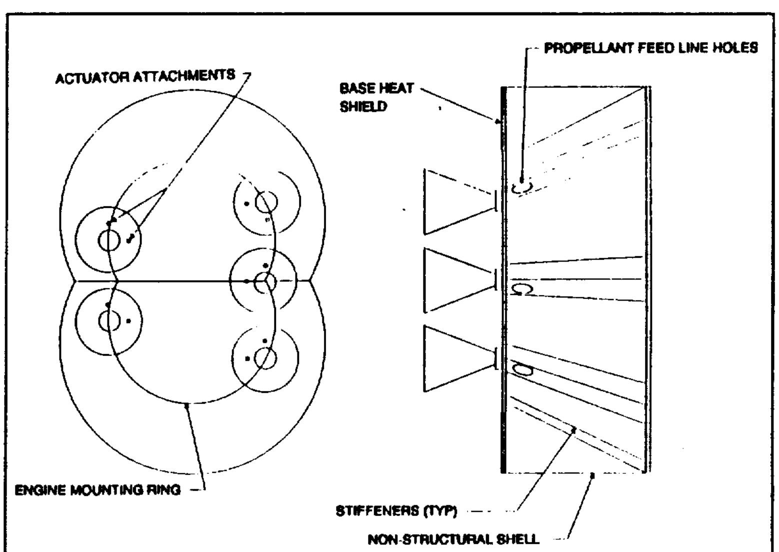


Figure 3-12. Orbiter Thrust Structure.

The orbiter wing is a titanium aluminide box beam with three spars. The two rear spars carry the wing bending through the aft fuselage. The forward spar is attached to the intertank structure by vertical links which take lift loads and permit the LO_2 tank to contract without transmitting longitudinal loads into the wing. A root rib carries the drag load back to the rigid attachment at the aft structure.

Titanium aluminide is in development for propulsion applications and for the NASP program. If it is not available to support the AMLS schedule, 1100 Titanium alloy can be used, with a slight weight penalty.

The orbiter wing skins are titanium aluminide sheet material, stiffened by super-plastically formed mechanically attached titanium aluminide stiffeners. The spars are conventional sine-wave shear-resistant beams of titanium aluminide, welded to upper and lower caps. Ribs are tubular trusses of titanium welded to titanium end fittings, and mechanically attached to the spars and skin panel.

The upper surface of the wing is capable of withstanding temperatures of over 1000 F and is not covered by TPS. This offsets the weight penalty of using titanium aluminide instead of a composite. The use of titanium aluminide and the resulting bare upper surface also enhances accessibility to the wing interior. Access is provided through doors in the upper surface structural panels. The lower surface is covered with hard-surface thermal protection panels to be described later. These TPS panels are mechanically attached to the wing structure. The TPS thickness will be sized to allow the lower structure to operate as closely as possible to upper surface temperatures to minimize thermal stresses. The wing leading edge is ACC, similar in concept to the Shuttle leading edge structural subsystem.

The wing tip fin construction and materials are similar to those used in the wing structure. Hard-surface and blanket TPS will be used on both surfaces of the tip fin as required. Control surface actuators are located in an insulated area aft of the rear spar for accessibility. Movable control surfaces may be constructed of ACC.

The hard-surface TPS panel concept proposed is based on the C-SiC material developed by the French company SEP for use on the HERMES reentry vehicle. These 12" by 12" panels, shown in Figure 3-13, provide a strong outer surface of the vehicle, and have excellent resistance to thermal and acoustic loads. Low-density layered insulation is used inside the panels, and flow barriers are used next to the orbiter skin. The mechanical attachments are buried in the gaps between tiles, and are covered with gap fillers to keep the fastener temperatures low. This low temperature is a key to removability and reusability of the TPS panels. SEP makes the following claims for the C-SiC panel TPS concept:

- lower weight owing to the optimized weight of the internal insulation materials
- improved impact strength owing to the high specific properties of C-SiC composites
- higher temperature limits capabilities
- maintainability due to mechanical attachment to the airframe.

The orbiter side and upper surfaces will be protected by flexible ceramic blanket insulation similar to that used on the Shuttle orbiter. The most common material now in use is Advanced Flexible Reusable Surface Insulation (AFRSI). These blankets are used at temperatures up to 1500 F. A more recent development, Tailorable Blanket Insulation

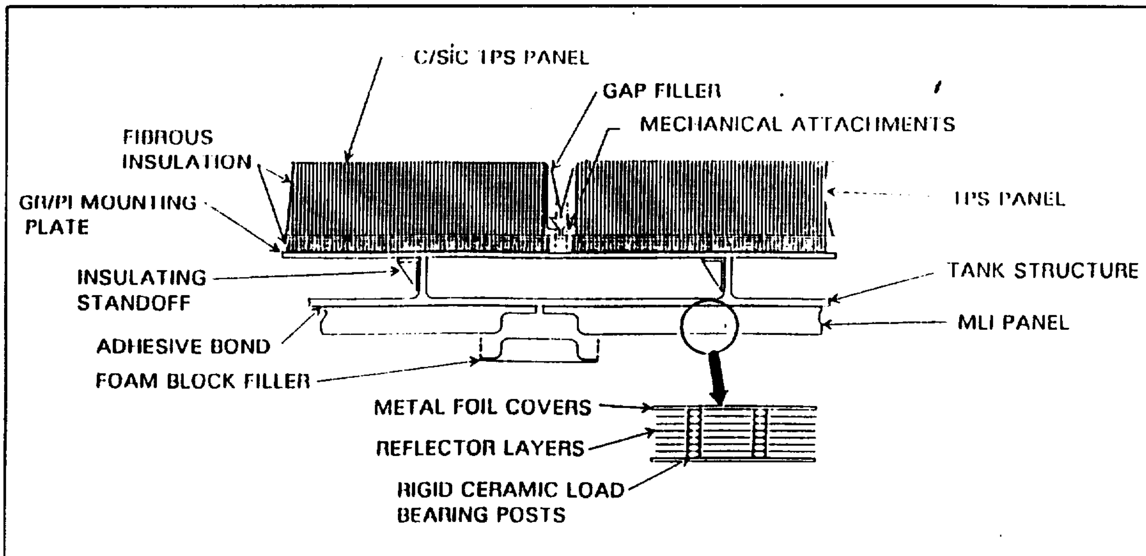


Figure 3-13. Orbiter Lower Surface Thermal Protection System.

(TABI) shows promise for service at higher temperatures. Waterproofing of these areas is a concern and needs to be investigated.

The standard approach to attaching the orbiter to the booster employs the three-point attachment system used between the Shuttle orbiter and the external tank. This arrangement is structurally efficient because the large thrust load is divided into two components and loads are applied to the shell structure generally in a tangential direction. However, this arrangement requires a large transverse beam to support lateral loads. This beam causes severe air flow problems which include high drag and unsteady aerodynamic flows.

An alternate approach is suggested, in which all thrust and normal loads are taken in centerline fittings, and longitudinal moments are resisted by two outrigger struts, as illustrated in Figure 3-14. Feed lines and umbilicals would likewise be located on the vehicle centerline. A study of the alternate (tandem fitting) interface concept concluded that the high thrust load (2,000,000 lb limit) would produce a moment which would have to be resisted by a thrust beam in both the booster and the orbiter. This beam is similar to the beam in the Shuttle external tank that takes SRB loads into the ET structure. The study concluded that, if the moment could be kept relatively small through close spacing between the orbiter and booster (18 inches was assumed in the study) the weights of the tandem and the three-point concepts would be similar.

The payload carrier is securely attached to the upper surface of the orbiter. A three-point attachment scheme isolates the payload carrier from tank contractions and simplifies installation and removal of the loaded carrier. Thrust loads are transmitted through two aft ball-joint fittings. The forward link takes vertical and side loads, but permits fore-and-aft motion. After installation of the structural attachments, the tunnel and seal must be attached at the forward end, the electrical/data interface plate must be attached, and aerodynamic fairings must be attached and sealed. Aerodynamic fairings will require an interface with the upper TPS blankets. The fairing connection must be easy to attach, and must seal against pressure differentials across the fairing.

Repair methods should be developed concurrently with the structural design. Application of the methods to specific structures in actual locations and orientations in the vehicle must be demonstrated. This is necessary to assure that the final design is repairable, which is a design requirement. Basic repair methods that could be used include:

- Welding cracks in the tanks
- Bonded boron-aluminum patches for dents/holes
- Hand layup of contoured patch and cure with vacuum bag and local heat

Some of the structural design concepts have not been completely developed, but they are believed to be efficient and practical approaches to specific AMLS design goals, considering materials and fabrication technologies that are expected to exist in a few years.

3.2.3 Propellant Tank Leak Detection

An instrumentation method is needed to detect cracks and léaks in AMLS cryogenic tanks and other structure. Early sensing of cracks and defects, before they assume critical proportions, permits repairs to be scheduled with minimal disruption of operations.

Various methods are available for detecting cracks in metal structures, including

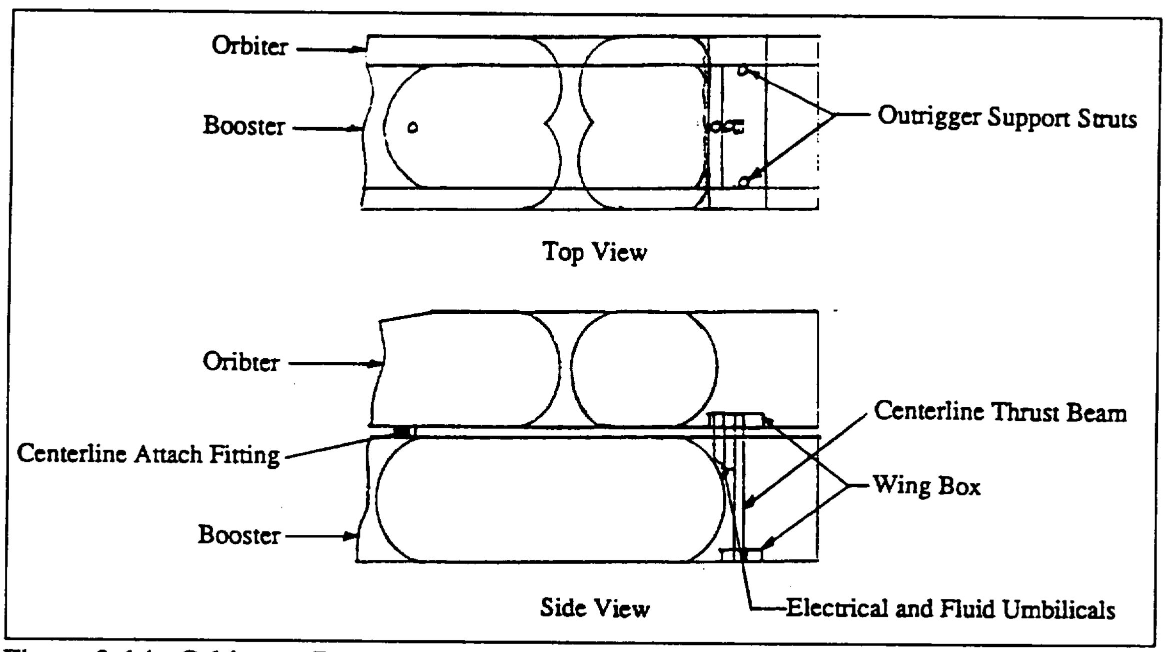


Figure 3-14. Orbiter to Booster Attachment.

radiography, ultrasonic, and acoustic emission. Recent work has been done to develop the capabilities of fiber optic sensors for detecting ultrasonic and acoustic waves. A network of such fiber optic sensors could be used to sense the structural state and to detect anomalies. Such a network would be part of an on-board sensing system that would periodically pulse and scan the structure, automatically analyze the return signals, identify changes from previous scans, and record the location of the discrepancy. The data could be downlinked to service personnel, so that immediate repairs could be initiated. Fiber optic networks are used on specific components and in other fields outside of aircraft/aerospace. Fiber optic networks for large aerospace structures should be fully developed by the time the AMLS design is finalized.

Several areas of development that would have to be undertaken to develop this technology are listed below. Successful development of this system would be very beneficial to the AMLS and other reusable spacecraft.

- Fiber optic sensors
- Acoustic pulse transducers
- Network design
- Scanning method
- Data analysis
- Installation and repair techniques

Other structural inspection techniques proposed for AMLS include:

- Closed circuit TV for visual inspection of interior of tank,
- X-ray for specific structural details,
- Eddy current inspections,
- Isotope radiographic for specific structural for massive sections,
- IR-scanning for possible insulation "leaks"

None of the proposed inspection techniques will require a technology breakthrough. TV, X-ray, Isotope, eddy current and IR-scanning have been used in airline maintenance for five to twenty-five years, with proven results.

3.3 MECHANICAL SYSTEMS

The major mechanical systems of the AMLS booster and orbiter include the landing gear, control surface and engine thrust vector control actuators, payload bay doors, interstage connections, and vehicle hatches and their associated pieces of attaching hardware. Two concepts employed in this section to enhance operability were the use of existing off the shelf equipment where feasible and the elimination of a centralized hydraulic system. The first concept played a major role in the landing gear selection while the second concept played a major role in the selection of actuators.

3.3.1 Landing Gear

The landing gear requirements listed below are intended to bring the AMLS vehicles into compliance with the commercial airline operating philosophy.

- Provide primary directional and deceleration control during landing roll out
- Withstand loss of 50% of wheel and tire assembles per strut without major structural damage to vehicle structure, gear, and attachments
- Support all normal ground handling operations at maximum landing gross weight
- Require no special structural inspections between flights
- Withstand barrier contact or contract with runway shoulder/overrun without major gear/structural damage

These requirements will result in the gear being designed with sufficient margin to accommodate landing anomalies and vehicle weight growth without placing operating restrictions on the vehicles. Figure 3-15 shows the general arrangement of the orbiter and booster landing gear.

The main landing gear was located longitudinally on the AMLS vehicles to carry 90% of the vehicle's weight. The gear height was then set to accommodate a tail scrape angle of 15 degrees with the vehicle center of gravity forward of the gear. The lateral location was assumed to be the fuselage wing intersection, and the overturn angle was verified to be within limits. A four-wheel bogey is baselined to achieve lighter tire loading and the capability to withstand a blowout without adverse effects. This arrangement also provides more braking surface thereby increasing the mean time between maintenance for the braking system. The brakes and all other landing gear actuators are electromechanical.

The nose landing gear on the AMLS vehicles was located on the vehicle centerline longitudinal location which places 10% of the vehicle's weight on the gear. The gear location takes advantage of major propellant tank structure for attachment. The gear uses two wheels to reduce tire loading and size. The gear would have the capability of swiveling up to 90 degrees with the torque links disconnected to facilitate ground operations in congested areas.

3.3.2 Miscellaneous Mechanical Systems

The miscellaneous mechanical systems are comprised of the various movable aerodynamic surfaces, the main engine thrust vector control (TVC) actuators, the payload bay doors and their associated hinges and motors, the interstage disconnect hardware and their protective doors and associated actuators, and finally the escape module and workstation hatches.

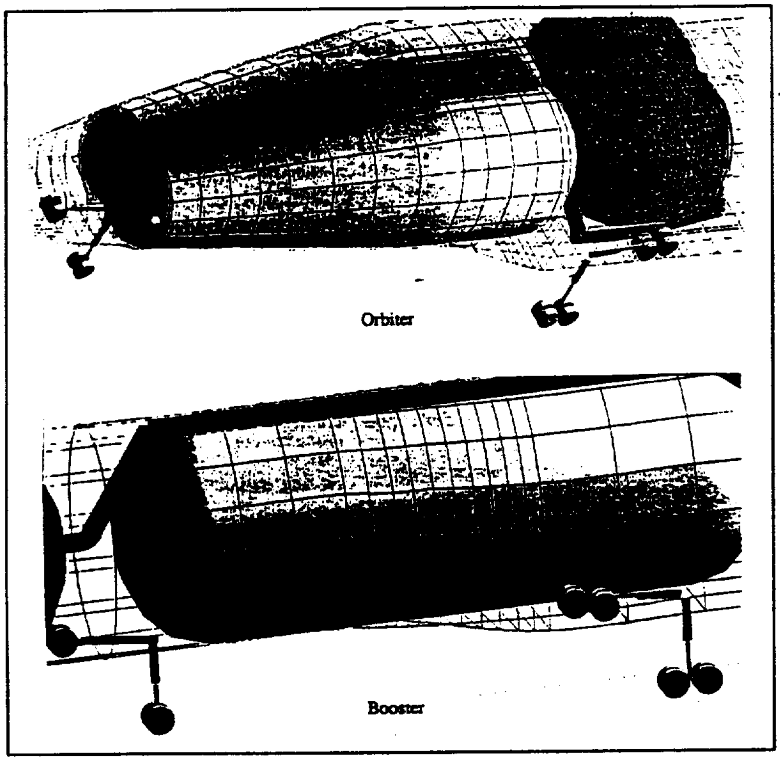


Figure 3-15. Orbiter and Booster Landing Gear Installation.

Electromechanical actuators or other electrical motor will be used as appropriate throughout these systems. There will typically be a mechanical connection consisting of bellcranks, pushrods, or torque tubes between the motor and the associated component being moved.

The PCS doors will be capable of being opened in a 1g gravity field without the use of any supporting strongback GSE. However, to reduce weight, the PCS motors will be 0 g only. Power to open the doors on the earth's surface will be supplied by GSE.

3.4 PROPULSION SYSTEMS

Various options are presented for the MPS/OMS/RCS. The final selection was based on the potential for that system to enhance operability while meeting basic performance requirements. In the case of the OMS/RCS options and final selection, Rockwell's Integrated Hydrogen Oxygen Technology (IHOT) study was used as a primary reference and guide.

The requirements and groundrules for selection of MPS/OMS/RCS were based on the AMLS program goals. The AMLS is to be a reusable, low maintenance system and this priority is reflected in the first two requirements listed below:

- Reusable system
- Reduce operations- Minimize number of different fluids used
- Performance- 40k payload
- Booster crossfeeds MPS propellant to orbiter
- NASA technology level 6 by year 2000
- No centralized hydraulic system

3.4.1. Propulsion System Options.

Options which met the above requirements are listed in Table 3-4. The characteristics of each of these options will be discussed briefly.

Main Engines. The primary design drivers of the STME are low cost and high operability. As a result, it will have lower specific impulse and higher weight than the other candidates. The lowest cost approach has required that the engine be expendable, but reusability may be imposed on the STME. The engine provides no feed system flexibility and has no bleeds.

For the AMLS the SSME would have to be modified to increase operability. These modifications would focus on the turbomachinery components, increasing their life and general robustness. The SSME would also incorporate changes, such as reduction in the number of welds, to reduce production costs. Improved health monitoring will also be incorporated to improve operability.

The plug nozzle engine is a revival of an old concept and could offer some advantages for the AMLS with its high performance and low weight. Because it is shorter and wider than the conventional bell nozzle engine, it integrates well into the vehicle layout. Complete prototype engines have been test fired in the past, and individual segments are now being tested. Because it is impractical to gimbal the entire engine, thrust vector control is a concern. Differential throttling and fluid injection are being evaluated to provide the TVC function.

Propellants. Storing the hydrogen and oxygen propellants for the main engines in the conventional subcritical or normal boiling point form requires large tankage but provides the most simple flight and ground systems. The hardware and procedures for loading, preconditioning, and supplying the engines have been developed for other vehicles and are well understood.

The use of triple point fluid reduces tank sizes, but it is difficult to handle and store because of the more critical temperature/pressure requirements. During loading and up to engine start, a continuous bleed from the vehicle to the ground is needed, requiring added ground interfaces. Critical procedures must be developed and validated.

Slush propellants result in the smallest tankage and therefore the lightest vehicle. Vehicle and ground systems and procedures are even more complex than those for triple point fluids. Mixers are required in the tank to prevent settling of the solid particles.

Propellant Cross Feed. Propellants can be transferred from the booster to the orbiter stage during first stage parallel booster/orbiter burn by providing booster tank pressure sufficiently high to overcome liquid head differences and pressure losses through the interconnecting plumbing system. A significant disadvantage of this method of transfer is that the required booster tank higher pressures, especially for the LO_2, can increase tank weight and adds residual weight in the form of booster ullage weight at MECO. An issue, common to the other options as well, is the large size required of the cross feed system. This system must be sized to provide propellants to the orbiter engines and must contain shut-off valves and disconnects.

Table 3-4. Candidate Propulsion System Options.

- MAIN ENGINE
  - STME
  - MODIFIED SSME (LaRC BASELINE)
  - PLUG NOZZLE/AEROSPIKE
- MAIN PROPELLANT
  - SUBCRITICAL (LaRC BASELINE)
  - TRIPLE POINT
  - SLUSH
- PROPELLANT CROSS FEED
  - PRESSURE TRANSFER
  - PUMP TRANSFER
  - GRAVITY TRANSFER
- PROPELLANT PRECONDITIONING
  - FLIGHT RECIRC PUMPS
  - GROUND RECIRC PUMPS
  - OVERBOARD BLEEDS
- OMS
  - SHUTTLE DERIVATIVE - STORABLE, PRESSURE FED
  - LH2/LO2 PUMP FED (LaRC BASELINE)
  - LH2/LO2 PRESSURE FED
- RCS - ORBITER
  - SHUTTLE DERIVATIVE - STORABLE, PRESSURE FED
  - LH2/LO2 PUMP FED (LaRC BASELINE)
  - GH2/GO2 PRESSURE FED
- RCS - ESCAPE MODULE
  - SHUTTLE DERIVATIVE - STORABLE, PRESSURE FED
  - LH2/LO2 PUMP FED (LaRC BASELINE)
  - GH2/GO2 PRESSURE FED

Pumps can be used to avoid the impact of high ullage pressures. These pumps must be large to provide the flow for all the orbiter engines and therefore require a large power supply, either electrical or from an auxiliary drive. The large plumbing system is also a concern.

If the booster LO_2 tank is forward while the orbiter tank is aft, the least complex system can be used because gravity can provide the transfer mechanism for the LO_2. The hydrogen will require pressurized transfer, but this requires relatively low pressure. The large plumbing system is again a concern.

Preconditioning. To ensure that propellants at the engine interface are at acceptable temperatures for engine start, vehicle recirculation pumps which move the warmer fluids from either the engine interface or from the engine itself back to the propellant tank can be employed. This approach, proven on the Saturn and STS programs, does add vehicle complexity with the resultant impact on ground operations needed for check out and servicing.

To simplify the vehicle systems, the recirculation pumps can be located on the ground. Additional vehicle to ground fluid interfaces are required.

Bleeding propellants from either the engine interface or from the engine back to the ground can be used but may not be as effective as pumped circulation. Fluid interfaces are also needed with this option.

Orbital Maneuvering System (OMS). The first option considered for the orbital maneuvering system (OMS) is similar to that for the current Shuttle orbiter. It uses nitrogen tetroxide as the oxidizer and monomethylhydrazine as the fuel. Because both propellants are toxic, special handling is needed, adding to operational costs. The propellants require either an RCS settling burn or low-G liquid acquisition devices within the tanks to ensure liquids are supplied to the engines at start. Much of the hardware developed for the current Shuttle program can be utilized, reducing development cost and risk.

A pump-fed liquid hydrogen/liquid oxygen OMS system has the operational advantage of common propellants with the main engine system. As with the first option above, low-G liquid acquisition is required. The pumps, pump drives, and controls needed to provide engine chamber pressure can be incorporated into the engine design or be separate. Either approach adds complexity, increasing hardware and operational costs.

A pressure-fed liquid hydrogen/liquid oxygen OMS system shares the common propellant advantage of the pump system above but provides less overall complexity. However, the propellant tanks must be heavier to withstand higher pressures than if pumps are used.

Orbiter And Escape Module Reaction Control System (RCS). The orbiter reaction control system (RCS) based on the current Shuttle system shares the characteristics of a Shuttle based OMS, including hazardous fluids impact on operations and low development costs.

A pump-fed liquid hydrogen/liquid oxygen orbiter RCS system has the same characteristics of the pump fed liquid hydrogen/liquid oxygen OMS system.

A pressure-fed gaseous hydrogen/oxygen orbiter RCS system must vaporize propellants, either on the ground or on the vehicle. Engine start is accommodated in zero-G. The propellant tanks must be heavier to withstand higher pressures than if pumps are used.

3.4.2. Propulsion System Selections.

A qualitative assessment of the candidate options is presented in Table 3-5 for the following categories. The selected option for each category is indicated by the "X".

- Meets requirements- How well the candidate satisfies the previously listed basic system requirements.
- Reduces operations- How effective the candidate is in reducing the cost of ground and flight operations.
- Reduces DDT&E and production costs- A comparison of candidate non-recurring costs.
- Reduces weight- Relative effect on vehicle dry weight.
- Reduces development risk- A measure of relative technology maturity for each candidate.

Table 3-5. Propulsion Options Evaluation.

OPTION	MEETS REQTS	REDUCES OPS	REDUCES DDT&E & PRODC	REDUCES WEIGHT	REDUCES DEVLMT RISK	SELECTED
MAIN ENGINE						
STME	MEDIUM	HIGH	HIGH	LOW	MEDIUM	
MODIFIED SSME	HIGH	MEDIUM	MEDIUM	MEDIUM	HIGH	X
MAIN PROPELLANT						
SUBCRITICAL	HIGH	HIGH	HIGH	LOW	HIGH	X
TRIPLE POINT	HIGH	MEDIUM	MEDIUM	MEDIUM	MEDIUM	
SLUSH	HIGH	LOW	LOW	HIGH	LOW	
PROPELLANT X-FEED						
PRESS TRANSFER	HIGH	MEDIUM	MEDIUM	LOW	LOW	X (LH2)
PUMP TRANSFER	HIGH	LOW	LOW	LOW	MEDIUM	
GRAVITY TRANSFER	HIGH	MEDIUM	HIGH	HIGH	HIGH	X (LO2)
PROP PRECOND						
FLIGHT PUMPS	HIGH	MEDIUM	LOW	LOW	HIGH	
GROUND PUMPS	MEDIUM	HIGH	MEDIUM	HIGH	MEDIUM	
OVERBOARD BLEEDS	MEDIUM	HIGH	MEDIUM	HIGH	MEDIUM	X
OMS						
SHUTTLE	MEDIUM	LOW	MEDIUM	MEDIUM	HIGH	
LH/LO2 PUMP	HIGH	LOW	LOW	MEDIUM	MEDIUM	
LH2/LO2 PRESS	HIGH	MEDIUM	LOW	MEDIUM	MEDIUM	X
RCS - ORBITER						
SHUTTLE	MEDIUM	LOW	MEDIUM	MEDIUM	HIGH	
LH2/LO2 PUMP	HIGH	LOW	LOW	MEDIUM	MEDIUM	
GH2/GO2 PRESS	HIGH	MEDIUM	LOW	MEDIUM	MEDIUM	X
RCS - ESCAPE MOD						
SHUTTLE	MEDIUM	LOW	MEDIUM	MEDIUM	HIGH	
LH2/LO2 PUMP	HIGH	LOW	LOW	MEDIUM	MEDIUM	
GH2/GO2 PRESS	HIGH	MEDIUM	LOW	MEDIUM	MEDIUM	X

3.5 POWER, EPDC, & ECLSS

Operability is enhanced by using common equipment between the orbiter and booster wherever they have common requirements. Since the booster is unmanned, it obviously doesn't need any ECLSS, and those systems are deleted from it. In the area of power generation and distribution and control, the two major decisions to be made were the distribution bus voltage level and the role of fuel cell versus batteries. The selection of a 270-volt fuel cell-powered system in both the orbiter and the booster was driven by the desire to reduce the size of the power system and reduce the number of different components being used and, therefore, maintained.

3.5.1 Electrical Power System (EPS)

Three program requirements impact the conceptual design of the EPS. The first requirement on the EPS is that power must be supplied to three distinct vehicle elements. These elements are the Orbiter, the Escape Module, and the Booster. Each system element must be able to operate independently during an abort emergency. A separate power source is needed for each vehicle element. Thus, the AMLS EPS will consist of at least three power sources.

The program also mandates dual fault tolerance upon all subsystems. The purpose of this mandate is to increase the probability of mission success. This requirement means that every system and subsystem must tolerate two failures before leading to an abort situation. As with all other subsystems, the EPS must also meet this fail-operational/fail-safe (FO/FS) requirement.

In order to reduce program risk and development costs, the program also requires that all technologies used in the AMLS be rated NASA technology level 6 by the year 2000. This also allows maximum use of technologies developed for other vehicles (NASP, SSTO, ALS, NLS).

Before identifying which types of power sources, bus voltages, etc. should be used in the EPS, it is necessary to determine how much power and what voltage the vehicle's components require. Examination of the three vehicle elements results in six power load categories: avionics, aero-surface control, thrust vector control (TVC), environmental control and life support systems (ECLSS), payload/workstation systems, and recovery systems. Since both the Orbiter and Booster share the launch and glide back loads, the two elements share similar loads during those portions of the mission. Under these circumstances, it is desirable to use common EPS components in the Orbiter and Booster. This approach may lead to reduced Design, Development, Test, and Engineering (DDT&E), manufacturing, and operational costs.

To define the power (peak, nominal, minimum) and energy requirements for the AMLS, a power history was generated for each vehicle element. Orbiter and Booster peak power loads were estimated based on three assumptions. The worst-case loads were assumed to occur when all electromechanical actuators (EMAs) used for TVC are required to move at 100% of their rated capacity. The EMAs used for AMLS TVC are assumed to draw 23 kW at 100% power (1/2 Shuttle equivalent). This is unlikely during a normal launch, but could occur during an abort maneuver. All other vehicle components were also assumed to be drawing maximum power. These include components from the avionics, ECLSS, etc. Known hardware loads were used when possible.

The FO/FS mandate also enters into the determination of EPS requirements, since sufficient power and energy capacity must remain after a single failure to perform the mission normally. The actual amount of extra capability carried on-board depends on the architecture of the EPS.

The mission timeline and activity plan contributes to the definition of the energy requirement. Since the AMLS mission is assumed to be five (5) days, the energy requirement may be the most important criteria for the selection of the power source types and quantities. Also, the selection of power source type should not preclude missions of longer duration.

The power history for the Orbiter and Booster is shown in Figure 3-16. The launch and descent/glide back portions of the power profile for both the Orbiter and Booster are very similar. Both the Orbiter and Booster have peak power requirements between 235 kW and 245 kW during launch and 25 kW to 35 kW during glide back. Therefore, as anticipated, using common EPS components for both elements is feasible. The most notable difference in the two profiles is the effect on total energy capacity that the longer duration of the Orbiter has. The total energy capacity is defined by the areas under each of the respective curves. The Orbiter requires 665 kW-hrs and the Booster requires 75 kW-hrs. The Orbiter's energy capacity must be nine (9) times greater than the Booster's. If common EPS components are to be used, then the dissimilar components must be capacity related.

Various options to meet the high rate requirements of both vehicles and the high capacity requirement of the Orbiter are listed and qualitatively assessed in Table 3-6. The first option listed is to combine a Shuttle-type fuel cell (long duration) and batteries (peak power augmentation) to meet the Orbiter requirements. The fuel cell may be eliminated on the Booster since its mission duration is short. This option efficiently fulfills the power and energy requirements using two power source types. Both of which provide high performance. However, this performance does not come without penalties. Batteries capable of supporting the high power requirement of the AMLS must have very high discharge rates. These batteries require substantial development and have numerous safety concerns. Also, the Shuttle-type fuel cell has failed to reach its designed

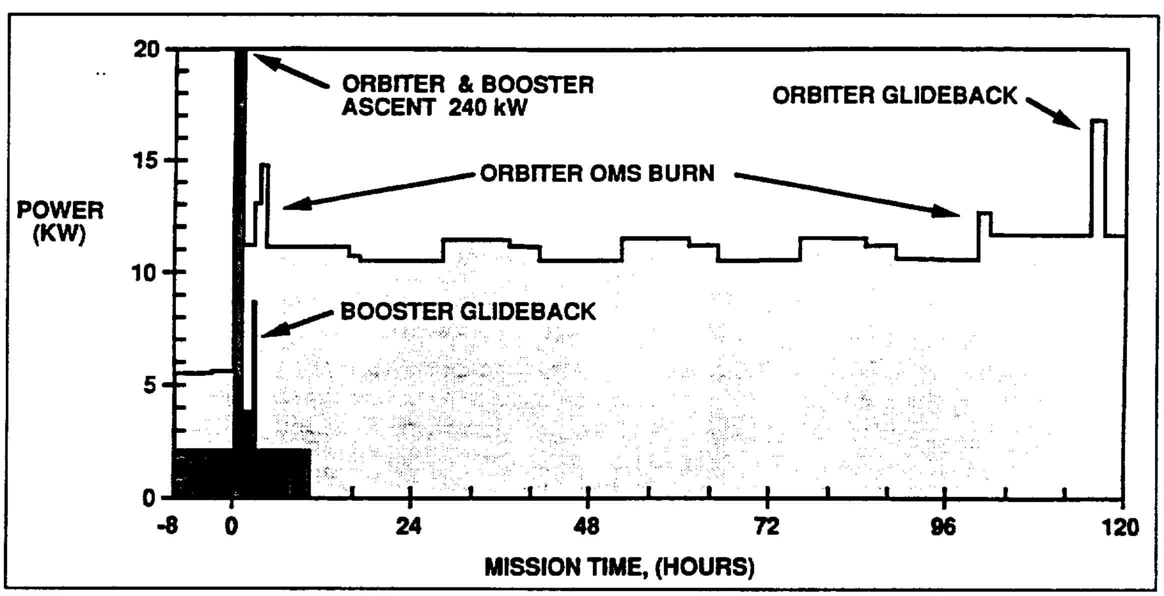


Figure 3-16. Power History.

maintenance schedule and is difficult to service.

The second option listed in Table 3-6 is to replace the batteries with a auxiliary power unit running on hydrogen and oxygen (H2/O2 APU). The H2/O2 APU is currently under development and could generate the high power required for the TVC. (Similar to the storable APUs on the Shuttle). The H2/O2 APU may have poor reliability as is true for the current Shuttle APUs.

The third option listed in Table 3-6 is to use the High Power Density (HPD) fuel cell (under development at International Fuel Cells) to provide all of the Orbiter's and Booster's power and energy requirements. The HPD fuel cell offers very high performance (projected current density of 4000 amps/ft2 compared to 250 amps/ft2 for Shuttle-type fuel cells) but will likely suffer the low Mean Time Between Maintenance (MTBM) rates of the Shuttle-type fuel cell.

Table 3-6. Power Source Options Need to Balance High Rate and Capacity.

FOUR SYSTEMS WILL MEET BOTH THE POWER AND ENERGY REQUIREMENTS:

ORBITER/BOOSTER	BENEFIT	LIABILITY
1. BATTERIES* (PEAK POWER) FUEL CELL (DURATION)	SEE BELOW HIGH kW, Wh/lb	SEE BELOW LOW MTBM
2. H2/O2 APU (PEAK POWER) FUEL CELL (DURATION)	HIGH kW HIGH kW, Wh/lb	POOR MTBF LOW MTBM
3. HIGH POWER DENSITY (HPD) FUEL CELL (PEAK POWER/DURATION)	HIGH kW, Wh/lb	LOW MTBM
4. DUAL MODE APU	HIGH kW, Wh/lb	POOR MTBF
* NON-RECHARGEABLE LITHIUM	VERY HIGH Wh/lb	SINGLE USE
RECHARGEABLE LITHIUM	HIGH Wh/lb AVAILABLE ~1995	INAPPROPRIATE FOR HIGH POWER
RECHARGEABLE SILVER-ZINC	MATURE, SPACE QUALIFIED	VERY HEAVY, 270 DAY LIFE

The final option listed in Table 3-6 is to use a dual mode H2/O2 APU. The dual mode H2/O2 APU combines a high rate and low rate turbine to efficiently provide both high and low power performance. This technology is very immature but could be used to meet the high power-short duration and low power-long duration requirements. Since the dual mode H2/O2 APU will be more complex, its reliability will probably be worse than the single mode H2/O2 APU mentioned above.

The HPD fuel cell option is recommended as the power source for both vehicles. The selection of the HPD fuel cell is justified in three ways. Since all options except the dual mode H2/O2 APU include a fuel cell, the substitution of the HPD fuel cell for the Shuttle-type fuel cell has a minimal impact. If the substitution is made, then the batteries and the APU of the first two options are unnecessary. The selection of a single power source type also yields numerous operational benefits during ground processing. The components, facilities, ground support equipment (GSE), personnel, procedures, etc. are all reduced if only a single type of power source must be serviced. For this reason, only the HPD Fuel Cell and the dual mode H2/O2 APU are acceptable. The HPD Fuel Cell was selected over the dual mode H2/O2 APU because it is further along in its development and will likely have higher reliability and lower maintenance requirements.

In order to minimize the number of wiring harnesses and wire sizes, the EPS will distribute power at only a single voltage level. Three bus voltages are available for use on the AMLS: (1) 28 Vdc (military/general aviation), (2) 130 Vdc (Space Station Freedom) , or (3) 270 Vdc (NASP). In the first table in Table 3-7, the Orbiter loads are broken-down by voltage into 28 Vdc, 130 Vdc, and 270 Vdc loads. The energy required at each voltage is also shown. The Booster's electrical distribution will be identical to the Orbiter's. Since power using both 28 Vdc and 270 Vdc must be provided, power conversion will be required. Current technology in power conversion provides 95% efficiency when dropping the voltage but only 65% efficiency when boosting the voltage. The power and energy losses resulting from the conversion process are shown for each voltage in the middle table of Table 3-7. The power source must provide power and energy equal to the sum of the Orbiter loads and the power conversion losses. The final table in Table 3-7 displays the results of this summation. The 270 Vdc is clearly the best option since both the power level and energy capacity are minimized. Line losses were not calculated but given the same power requirement for either transmission voltage level the current level of the 28 Vdc lines would be an order of magnitude higher than the 270 Vdc lines. Since line losses are directly proportional to current level the 270 Vdc option would also minimize line losses. Therefore, the 270 Vdc bus voltage will be used.

Since the results of the preceding analysis depends on the efficiency of the power conversion process, the impact of increasing efficiency (by technology advancement) was studied The left graph in Figure 3-17 represents the relationship between boost conversion and drop conversion based on the estimated Orbiter loads. The relationship is characterized by the equation: $Nb * P270 = Nd * P28$ (where, Nb is the boost efficiency, P270 is the 270 Vdc power requirement, Nd is the drop efficiency, and P28 is the 28 Vdc power requirement). The shaded region of the graph indicates those combinations of

Table 3-7. Selection of Bus Voltage Impacts Power and Energy Requirements.

ESTIMATED VEHICLE LOADS

Component Voltage	Peak Power kW	Energy kW-hr
28 Vdc	10	490
130 Vdc	- na -	- na -
270 Vdc	230	175
TOTAL	240	665

POWER CONVERSION EFFICIENCIES:
VOLTAGE BOOST – 65%
VOLTAGE DROP – 95%

LOSSES DUE TO CONVERSION

Buss Voltage	Peak Power kW	Energy kW-hr
28 Vdc	81	61
130 Vdc	81	86
270 Vdc	1	25

POWER SOURCE REQUIREMENTS

Buss Voltage	Peak Power kW	Energy kW-hr
28 Vdc	321	726
130 Vdc	321	751
270 Vdc	241	690

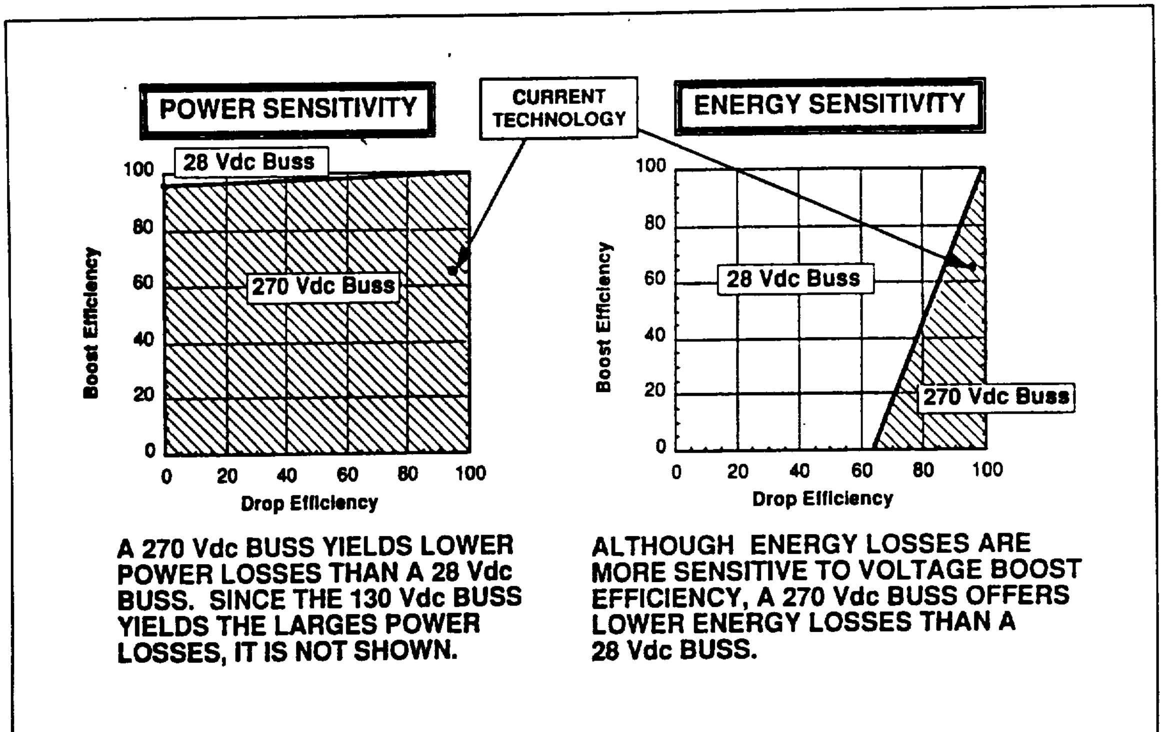


Figure 3-17. Power Conversion Technology Impacts Bus Voltage Selection.

boost and drop efficiencies which favor the 270 Vdc bus voltage selection. As shown, the boost efficiency must be increased to nearly 100% for the 28 Vdc bus voltage to be favored. The right graph in Figure 3-17 shows the same relationship between boost and drop conversion but comparing energy losses. Again, the 270 Vdc option is favored over the 28 Vdc option. However, the energy losses are more sensitive to increasing boost efficiency. Still, the boost efficiency must exceed 95% to favor the 28 Vdc bus voltage.

Figure 3-18 shows a schematic representation of the Orbiter and Booster EPS. The Orbiter's EPS will consist of four (4) HPD Fuel Cells generating 80 kW each at 270 Vdc. Only three are needed during the launch phase to meet the 240 kW peak power requirement. The fourth fuel cell is to ensure that the loss of a fuel cell during ascent will not lead to an abort situation (groundrule). Once in orbit, two of the fuel cells will be shut down since only two fuel cells are required for reentry and glide-back power. In the event of a failure on-orbit, one of the dormant fuel cells can be restarted. The fuel cells are integrated with the ECLSS (potable water generation) and OMS/RCS (common H2/O2 tankage). The electricity produced by the fuel cells is distributed to the components over a 270 Vdc bus. All power conversion is done at the component level.

The Escape Module's EPS will consist of two lithium thynol-chloride (Li-SClO2) batteries. The batteries will provide 270 Vdc power to the same bus as the Orbiter EPS to simplify integration of the emergency power supply. The lithium batteries (not rechargeable) have a active open circuit life of several years with some loss in efficiency. Therefore, they can be activated when they are installed and replaced when needed. The power and energy loads required for the Escape Module have not been estimated but are thought to be very low.

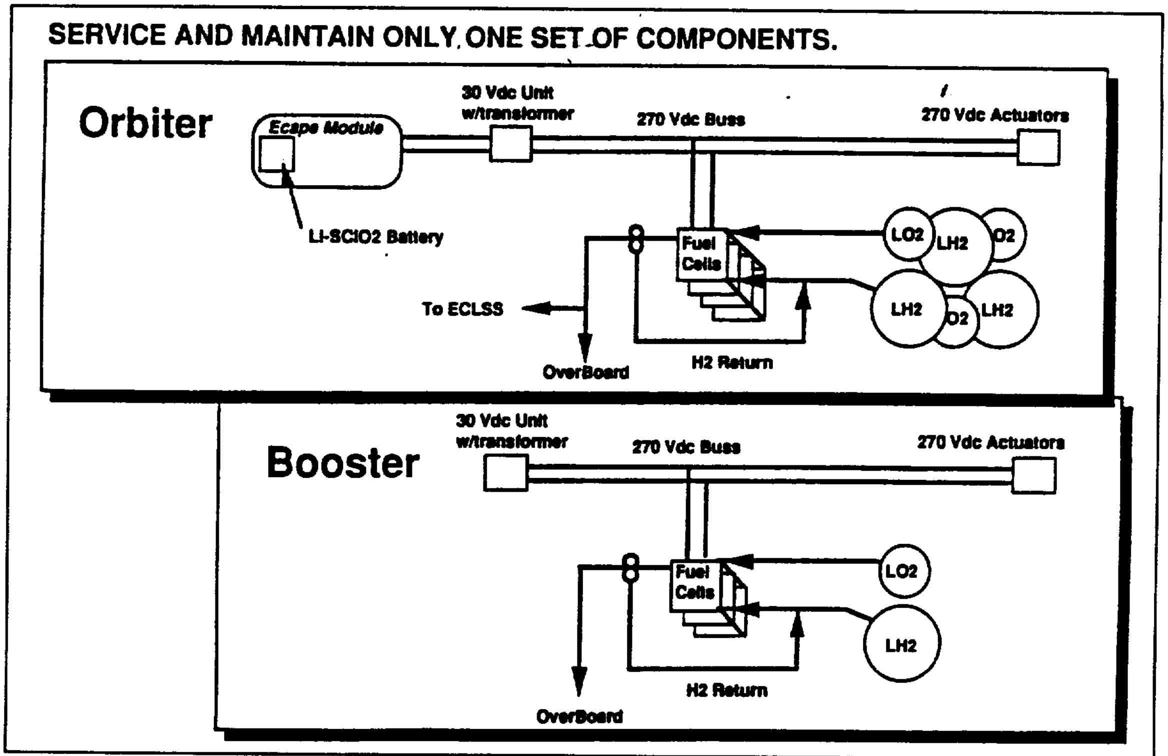


Figure 3-18. Orbiter and Booster Utilize Common Components.

The Booster's EPS will be nearly identical to that of the Orbiter's, except that only three fuel cells will be used, to produce the same degree of redundancy as in the orbiter, and there is no interface with an ECLSS. The fuel cell product water will be dumped directly overboard. In all other respects the two systems will be identical. Maximum similarity was selected to reduce ground operations.

3.5.2 Environmental Control And Life Support System (ECLSS)

The normal operations of the AMLS requires that the Orbiter provide a long-term, safe (even comfortable) environment for the crew and a benign environment for the many subsystems and components. The ECLSS requirement is derived from the need to increase the probability of mission success and applies throughout the three mission phases: Ascent, On-Orbit, and Descent.

During an abort situation where the need exists to separate the Escape Module, the ECLSS requirement is different. Now the emphasis of the ECLSS is simply on providing a short-term, survival-oriented environment. The crew will egress as soon as possible after the water landing. It is assumed that the crew may remain in the vehicle for up to six (6) hours after impact to allow ample time to remove injured personnel.

There are nine (9) functions that will be considered under the heading of ECLSS. These functions are defined below:

- Atmospheric Pressure and Mixture Control: Provides a 14.7 psi, oxygen/nitrogen atmosphere at sea-level conditions.

- Carbon Dioxide (CO_2) Removal: Removes metabolically-generated CO_2 from the cabin atmosphere to maintain acceptable CO_2 levels.

- Trace Contaminant Removal: Removes trace contaminants such as carbon monoxide, methane, and ammonia which are also metabolically-generated. Additional contaminants result from off-gassing from cabin materials.

- Thermal Control: Regulates the temperature of the cabin air, the water supply, avionics, and other components. Also provides heat rejection from the vehicle.

- Humidity Control: Regulates the cabin dew point to minimize moisture-related equipment problems and crew discomfort.

- Fire Suppression: Eliminates combustion inside the cabin and neutralizes the source of the fire. Give fire warning to the crew.

- Water and Food Supply: Provides drinking/cooking (potable) water and food for the crew depending of mission length. May also include water for hygiene use.

- Waste Management: Handles all forms of liquid and solid wastes, in particular, human excrement.

- Crew Accommodations: Provides sleeping, food preparation, storage areas as required. Includes human factor issues which affect the crew's performance.

The ECLSS duration requirements for the normal operation of the Orbiter are identical to those for the Shuttle. All Shuttle, and even some SSF requirements must be met. During the abort operation, the ECLSS duration requirements are less stringent. It is necessary only to ensure the crew's safety until the crew exits the Escape Module. Table 3-8 lists the duration requirements for each of the ECLSS functions under normal and abort operations.

Table 3-8. Duration Determines Which ECLSS Functions Are Required And At What Level.

FUNCTION	NORMAL OPS	ABORT OPS
OPERATIONAL DURATION	35+ MAN-DAYS	<6 HOURS
ATMOSPHERIC PRESSURE CONTROL	14.7 psia	TBD
ATMOSPHERIC MIXTURE CONTROL	20% O2/ 80% N2	TBD
CO2 REMOVAL	ppCO2 <0.3 psi	NONE, VENTED
TRACE CONTAMINANTS REMOVAL	YES	NONE, VENTED
THERMAL CONTROL	65°F - 85°F	TBD
HUMIDITY CONTROL (DEW POINT)	40-60	NONE
FIRE SUPPRESSION	YES	YES
WATER AND FOOD SUPPLY	YES, SHUTTLE	SURVIVAL
WASTE MANAGEMENT	COMMODE, TRASH STORAGE	NONE
CREW ACCOMMODATIONS	SLEEPING AREA, GALLEY	LIFE RAFT, RESCUE GEAR

Of the nine (9) functions that the ECLSS must provide, five (5) entail technology selections which will be discussed in the following paragraphs. Wherever possible options that are "off the shelf" will be used to reduce DDT&E costs and/or regenerative options will be used to reduce consumables and enhance mission duration..

The atmospheric consumables (oxygen and nitrogen) can be stored as either gases or as liquids (cryogens). The gaseous storage is simple and has no boil-off losses but requires large, heavy tanks. Liquid storage, on the other hand, has lower volume requirements, but has boil-off losses that become more important as the mission duration increases. The ECLSS will supply liquid oxygen from the common ECLSS/EPS/OMS/RCS tankage. Nitrogen for leakage make-up and repressurization will be provided from gaseous storage.

Carbon dioxide removal can be accomplished with lithium hydroxide (LiOH) canisters (used on Shuttle), solid amine (like the HS-C material used in the Regenerative Carbon-dioxide Removal System (RCRS) for the Extended Duration Orbiter (EDO)), or zeolite beds (used on Skylab). The LiOH canisters provide simple, efficient CO_2 removal, but must be replaced periodically during the mission. The last two options give regenerative CO_2 removal which eliminates consumables but increases the complexity of the system. Carbon dioxide removal from the cabin by the RCRS is recommended. The RCRS may be used for short periods (~20 min) during ascent and descent without an external vacuum. For any additional requirement, up to several hours, an open loop system without CO_2 removal will be adequate.

Two thermal control approaches are considered. The passive cooling approach is to conduct heat loads from low power components into the vehicle's structure. The active cooling method uses convective heat transfer to carry the energy to the heat rejection system. A radiator, flash evaporator, or cryogenic fluids are used for heat rejection.

Thermal control will be achieved in three ways. Since most components on the AMLS vehicle use little power, these loads will be conducted into the vehicle's structure. The ECLSS and the EPS both require active cooling. A fluid coolant loop will interface with a condensing heat exchanger (CHX) in the ECLSS and the fuel cells in the EPS. The coolant loop will transport heat to a body-mounted radiator on the sides of the transfer tunnel and/or to a cryogenic heat exchanger in the MPS. The cryogenic heat exchanger will boil-off and vent some of the MPS residuals. Several times the amount of MPS residuals needed for thermal control will be available. The radiator is the primary heat rejection system while on-orbit and the cryogenic system is the only heat rejection used during ascent and descent and will handle peak on-orbit requirements.

Removal of cabin humidity is accomplished by condensation (in a condensing heat exchanger), absorption (in silica gel, etc.), or adsorption (limited in the RCRS). The condensing heat exchanger and the RCRS are regenerative Shuttle hardware. Silica gel offers a simpler but heavier system. The condensing heat exchanger will be used to provide humidity control and will interface with the potable water storage. This is identical to the current Shuttle system.

The fire suppression system should use either Halon 1301 (Shuttle), carbon dioxide, or nitrogen to smother the fire. The last two options integrate other ECLSS systems to reduce the need for a separate system. Halon 1301 will require a separate ECLSS system to perform the function. Based on its technical maturity Halon 1301 fire suppression system will be used in all habitable volumes. The system will include both built-in and portable fire extinguishers.

Trace contaminants are neutralized with an ambient temperature catalytic oxidizer (ATCO) as is done on Shuttle. Additionally, the RCRS has shown some capability of trace contaminant removal. This capability is being evaluated under IR&D.

Because of the abort scenario's short duration a different ECLSS approach is used. The crew will wear partial pressure suits during the launch. If there is a need to abort the mission and separate the escape module, oxygen (gaseous storage) will be provided through the partial pressure suit. Cabin pressure will be maintained by adding nitrogen (gaseous storage). The carbon dioxide and trace contaminants will be exhausted overboard as the cabin vents. No active removal is required since the crew would have to remain in the vehicle in excess of 8 hours to raise the CO_2 concentration to dangerous levels.

Since the crew will wear the Shuttle partial pressure suit, survival equipment and supplies will also be included. This equipment will include back-up oxygen supply, an individual life raft, a small supply of stored water, and miscellaneous search and rescue (SAR) aids.

The workstation and escape module ECLSS are integrated during normal operation, see Figure 3-19. The RCRS, CHX, and ATCO are located in the Workstation. The cabin atmosphere is recirculated between the escape module to the workstation through ducting inside the transfer tunnel. Oxygen and nitrogen are added to both the escape module and workstation to meet consumption and leakage requirements. Water produced in the fuel cells and the CHX is stored in a water accumulator inside the workstation. During an abort, the escape module carries its own stored oxygen and nitrogen but uses the same distribution system that the integrated system does.

The thermal control for the Booster will share common components with the Orbiter. Since the Booster is not a manned vehicle it does not require a radiator or any ECLSS interfaces. Therefore, all thermal loads will be conducted to the Booster's structure or sunk into the MPS cryogenic residuals. An estimate of cryogen boil-off indicates that less than 15% of the MPS residuals are required to support the heat rejection requirement.

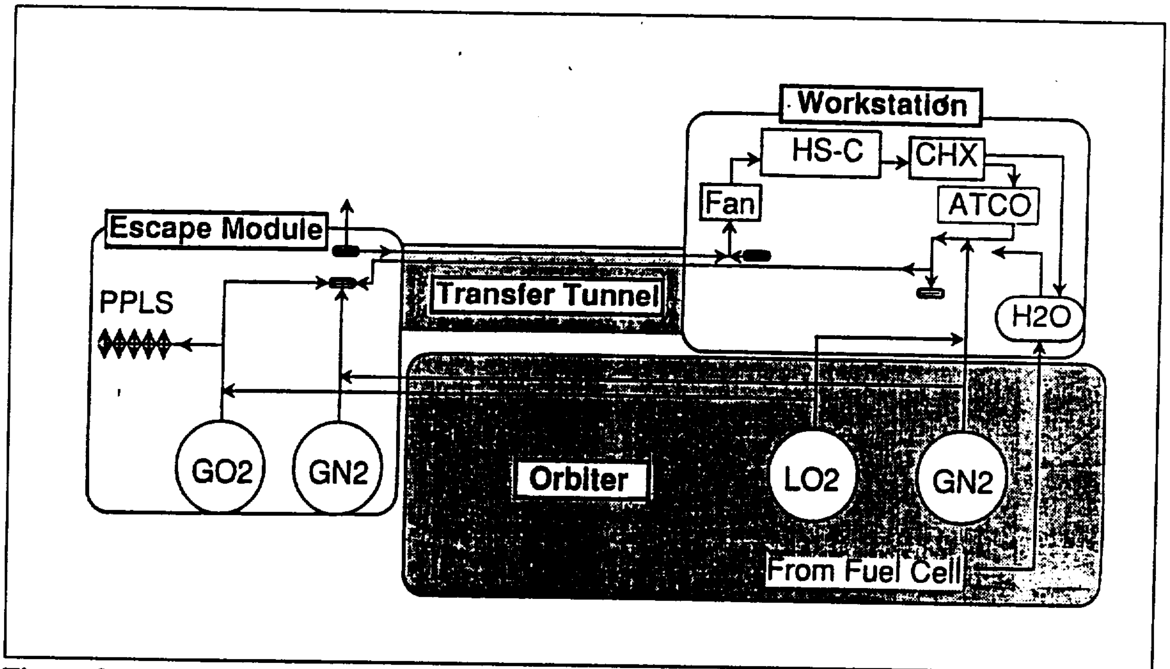


Figure 3-19. Workstation and Escape Module Use Integrated ECLSS.

3.6 AVIONICS

The avionics systems of the AMLS will make major use of off-the-shelf equipment. In many aspects the requirements of the AMLS are no different than any other commercial airliner and benefit is made of this by using existing equipment with well established operating histories and repair records. This philosophy will also result in the availability of a large number of spares and the ability to replace component boxes without regard to manufacturer since components meet common specifications.

Besides the AMLS functional requirements that have been addressed in previous space vehicle designs, the one area which will be implemented in depth is total vehicle self-check with auto re-certification capability for quick turn around after verifying all systems to be nominal. Advances in data storage technology and processing capability will allow for full automated maintenance and check-out support. Principal avionics functional requirements are listed below:

- Guidance, navigation, and flight control
- Communications and tracking
- Displays and controls
- Instrumentation
- Data processing
- Support for all mission/mission phases
- Uplink/downlink capability
    - Telemetry
    - Health monitor parameters
    - Redundancy status
    - Performance parameters
    - Communications

- Fault management
  - Autonomous fault detection/fault isolation using bit/bite technology
  - Distributed processing using dynamic resource allocation
  - Status reporting to designated health monitoring cpu(s)
  - Redundancy based on "probability of failure" at the functional level
  - Satisfies fail op/fail safe
- Onboard automated maintenance support
  - Automatically identifies hardware anomalies to board level
  - On-line service manual for technicians
  - Automatic re-certification
- In and out of cockpit operations

This section describes features of the selected AMLS avionics system concept and architecture which enable the cost-effective operation of the system as a whole. The flight articles provide rapid and efficient access to all the avionics systems for inspection and maintenance. The avionics system design reflects modern commercial and military approaches to integrate avionics systems and provides an effective system for continuous and automatic vehicle health monitoring. Finally, candidate instrumentation items and their functions are described.

3.6.1 Accessability

Access to facilitate ease of maintenance for subsystems in general and avionics in particular have been a major design emphasis. The preferred location is the underside of the vehicle where access can be gained without GSE. Since access when the vehicles are mated was also desired the underside location was only feasable for the booster. The location choosen for the orbiter is the side of the body, above and just aft of the wing leading edge. This location was felt to be the best possible for the orbiter since it provides good accessability at all times, and is in what is expected to be a low heating area thereby minimizing possible TPS sealing problems. On the booster, the vehicle's skin forms the base of the avionics rack which drops down on four linear actuators. In the down position the multi-tier rack is accessable from all sides. On the orbiter the vehicle skin acts as a hinged door. Avionics boxes are mounted to the inside of the door and in the compartment to maximize accessability and effective use of the available space. In either vehicle no boxes will be mounted behind another.

3.6.2 Candidate Architecture

The selection of an advanced cost-effective avionics architecture for the AMLS from off-the-shelf systems is the result of years of IR&D at Rockwell to analyze optimal configurations and select ideal components directly applicable and readily available with minimal applications-unique hardware and software modifications. Many advances have been made in data processing, health monitoring, navigation, displays and controls and data communications since the development of the Space Shuttle avionics suite. Other areas such as transponder technology, RF Communications, telemetry systems, and power control circuitry have been more evolutionary and refinements have been more subtle.

Figure 3-20 outlines a concept for a simple, highly reliable, contemporary avionics design for the AMLS which allows for fail-operational, fail-safe vehicle performance over the mission profile. A feature of the architecture concept presented here is the similarity of architectures between the recoverable booster and the recoverable space vehicle. During the boost phase, the avionics systems of both vehicles, while independent, can share each other's resources via the redundant FDDI-type, bi-directional high speed optical links, which soft-disconnect during separation using "trans-opticals" and "rec-opticals" at the interface. This allows up to six voting processors to participate if necessary in all boost phase operations, utilizing space vehicle processors and the space vehicle redundant high speed optical disk memories for contingency reconfigurations.

The heart of the data processing complex is a triple redundant card cage, two voting processors per card cage design driving four data busses, configured in such a way that any processor or data bus can perform all mission requirements if necessary, with small sacrifices in operational capability.

High speed microprocessor technology and VHSIC (Very High Speed Integrated Circuitry) has made the Shuttle main data processor obsolete because of the inherent speed and memory limitations of last generation technology. The Shuttle processor depended upon a complex processor/input-output processor architecture and a unique and complex software language (HAL/S). HAL/S was developed for the AP-101 derivatives on Shuttle is all but unknown to present day programmers.

Contemporary card-mounted processors, such as ASCM (IBM and Honeywell), JIAWG (many companies), Honeywell B5 or other processor families with 1553 and very high speed fiber and copper direct buss architectures supported in Ada will be the optimal choice for the next generation vehicles because of their availability, ease of produceability, relative low cost, adaptability of Ada software from advanced airline applications, and modular nature allowing rapid configuration for differing levels of required mission reliability.

A feature of contemporary processor technology is the inclusion of health check and vote-control busses for buss cross-strapping, two-out-of-three box voting for mission critical events, and cyclic overhead ultra-high speed processor self-test verifying processor performance at varying rates dependent upon the operation being performed.

To minimize or eliminate the need for costly and time consuming pre-flight I-load/verify procedures air data from advanced sensors on both the booster and orbiter (for redundancy) will be available during the boost phase. This will allow closed loop control of the vehicle's orientation (weather-cocking) during boost thereby minimizing aerodynamic structural loads to the vehicle's during ascent. The advanced air data system required for this is in development and will also be used by the orbiter during re-entry and landing.

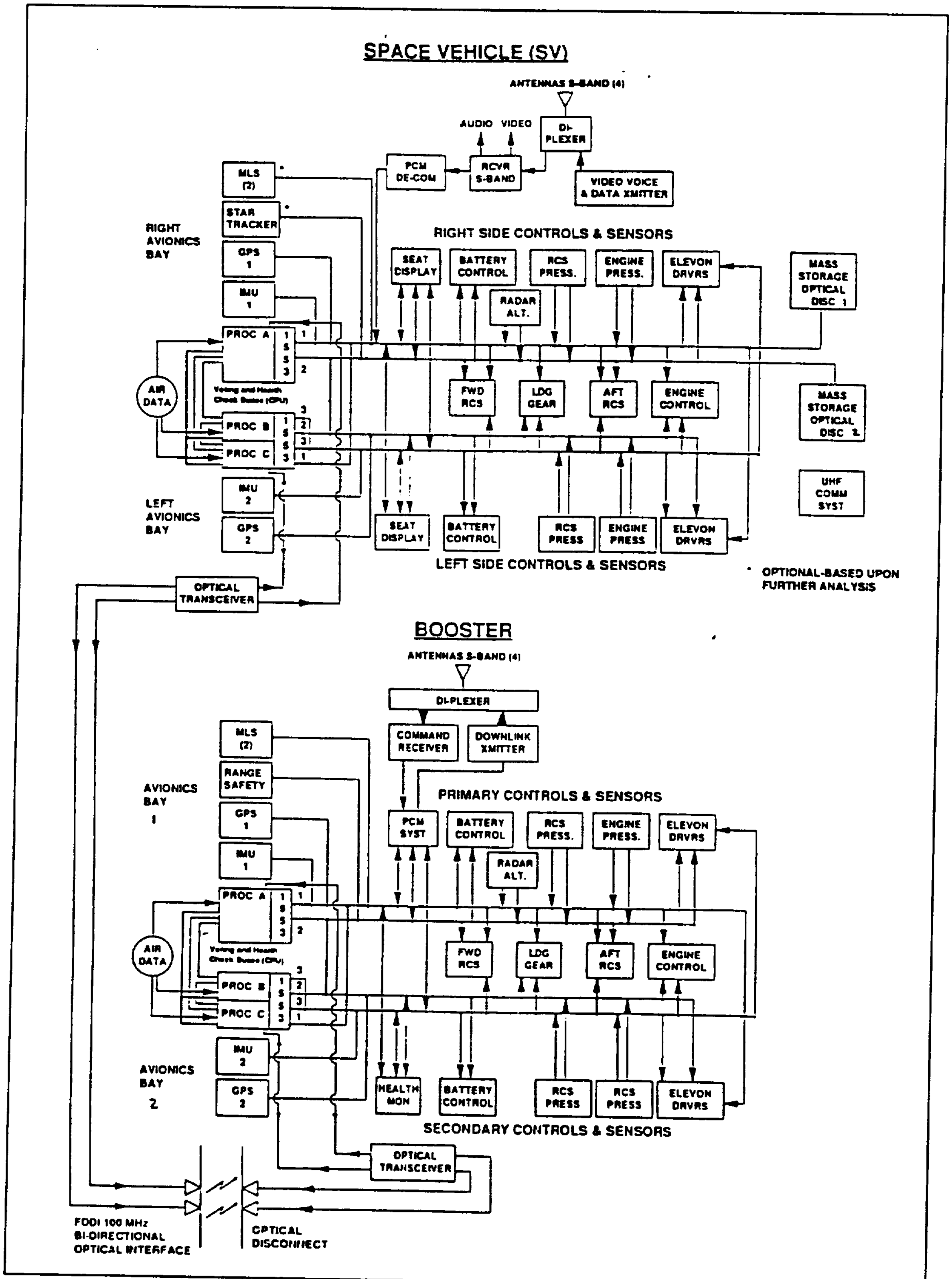


Figure 3-20. Generic AMLS Avionics System Architecture.

S-band and telemetry components will be selected from existing booster and space vehicles programs presently in production. First choice is compatibility with the Space Station Approved Parts List.

GPS and Glonass with further refinement will provide the primary navigation references and vehicle orientation for the combined or separated vehicles. The optical IMU's and accelerometers are updated by satellite references at periodic intervals. Texas Instruments has shown vehicle orientation as well as position in space is determinable with GPS. Earth limb or sun sensors can be provided for back-up, if necessary. Experience may delete the requirement for the back-up sensors, if the GPS/Glonass system has inherent redundancy.

The potential use of GPS for category III (fully blind) landings has been sucessfully demonstrated by Honeywell and Langley dramatically revealing the possibilities of differential GPS for autoland. While the tests did reveal a little better "tightness" of deviation from centerline with the Microwave Landing System, it is felt that the Microwave Landing System should be included on early flights until it is demonstrated that the GPS autoland is equally capable.

In accordance with the present move away from hydraulic controls and maintenance-intensive hydraulic APU's, electro-mechanical actuators (EMA) have been selected for the AMLS. The aerosurfaces are controlled by EMA's, utilizing 270 volt DC actuators. The elevons, the RCS, the pressurization, landing gear deployment are all EMA and solenoid driven.

Key power supply circuits will be made inherently redundant using such elements as the Autonetics Power Voter, with partial failures flagged during box-by-box vehicle status word check. The radar altimeter will be used for vehicle(s) re-entry and for assisting in the docking maneuvers of the Space Vehicle with Space Station. A battery powered GPS with the alternative of a star tracker is maintained in reserve in the Space Vehicle for absolute limp-home manual return to Earth. It is truly not felt this will ever be required, but is part of the vehicle manifest.

Space vehicle control is dual, with right and left seat having interchangeable displays much as contemporary 767/777 aircraft cockpits. Vehicle instrumentation is of the glass cockpit type, eliminating the maintenance requirements for mechanical type instruments. Current all purpose displays have MTBF's of 10,000 hours using best commercial grade components. Multiple displays with full switchover capability will yield mission reliabilities in the "least likely to fail" range.

Borrowing from a technique used in the next generation commercial aircraft equipped with "glass" cockpits, an emergency self-powered independent processor monochrome (low current demand) flight director will be central to both sides of the pilot seating for flight support during a major loss of avionics power, or other anomoly causing failure of the glass cockpit instrumentation system.

3.6.3 Avionics System Characteristics

The primary design philosophy behind the modern aircraft avionics system is the integration of very large quantities of information about the aircraft itself, its flight characteristics and its environment. The primary method of integration is through the Electronic Flight Instrument Systems (EFIS) being provided by all of the major avionics manufactures.

The primary method of display for EFIS is by Flat Panel Display (FPD). Here the advantages are higher reliability, lower cost, a smaller package, and improvement in alpha/numeric and graphic display capabilities over Cathode Ray Tube (CRT) technology.

The major thrust in avionics integration is the computational heart of the EFIS. In the case of Collins' Pro Line 4 system, this is handled by the Integrated Avionics Processing System (IAPS) which is similar to the Integrated Avionics Computer (IAC) of Honeywell's Primus 2000. The main feature of these systems is to provide a central maintenance function which supports maintenance monitoring for performance of the avionics and all aircraft systems and environments. The system is capable of handling any sensory input and applying logic to it while replacing all the normal annunciator lights with messages that appear on one of the displays in priority order.

Coupled with the EFIS is an on-board Aircraft Communications Addressing and Recording System (ACARS) which is a digital data link used to replace voice communications for routine types of functions to provide a downlink of maintenance information. Here the return on investment would come in the form of reduced down time for the vehicle.

Using a laser inertial reference system such as Honeywell's LASEREF II Inertial Reference System (IRS), which is built around a compact ring laser gyro, integrated with a Global Positioning System (GPS) receiver will provide a bounded 100 meter position error and offers the capability to re-initialize an IRS in-flight without loss of accuracy.

Additionally the EFIS allows integration of the Traffic Alert and Collision Avoidance Systems (TCAS) and Mode-S transponder to provide a mini-air traffic control display with heading and azimuth to other aircraft along with integrated aircraft response for operation in crowded airspace.

3.6.4 Candidate Instrumentation

To minimize program costs and provide maximum utility, ARINC 600 spec high MTBF avionics are selected where applicable, with proven performance histories to guarantee success and minimize support logistics. Fiber optic data busses, "glass cockpit" displays, redundant processors, heads-up-displays, and guidance/navigation avionics will be off the shelf components. Selection criteria for AMLS are listed below:

- Supports pad activities via telemetry
  - No T-O umbilical
  - Minimize GSE
  - Reduces pad manpower requirements
- Self check on power-up only
  - No routine ground checkout
  - Automated power up from launch complex
- Failure data stored in non-volatile memory at lru level
  - Reduces bus/cpu activity
  - Failure data down linked during "non-critical" flight periods
- Easily accessible avionics
  - Drop down/swing out avionics bay
- All "dc" electrical system
- Fiber optic data buses
- Medium rate flight control actuator
- Glass cockpit
- LRU
  - Passive cooling
  - ATR rack mounting
  - Components per ARINC 600 using blind mated assemblies
  - Off the shelf
  - High MTBF
- HUD functions
  - On-orbit
  - Atmospheric flight

Electronic Cockpit Controls. Review of available advanced technology displays and control systems has focussed upon glass cockpit systems developed by Rockwell/Collins and Honeywell for advanced aircraft systems. The system developed by Collins for the Saab 2000 fighter aircraft appears to best meet the present AMLS requirements and selection criteria. A qualitative assessment of the displays and controls candidate options is shown in Table 3-9.

Navigation and Attutude. The navigation and attitude systems will be based upon laser fiberoptic gyros and Global Positioning Satellites (GPS). Recent developments in GPS applications demonstrated that GPS can also provide attitude control, either direct or as periodic updates to a conventional ring laser

Table 3-9. Displays And Controls Candidates.

COMPONENT/FUNCTION	BENEFIT	DISADVANTAGE
COLLINS	IN SERVICE WITH SAAB 2000 AND BEECH STARSHIP. AVAILABLE. WILL HAVE AT LEAST A 10 YR OPERATIONAL HISTORY.	MAY BE MORE ADVANCED SYSTEMS ON MARKET BY 2000
HONEYWELL	ADVERTISED IN BOEING 777 AS MOST ADVANCED GLASS COCKPIT. WILL HAVE AT LEAST 5 YEAR OPERATIONAL HISTORY.	FIRST USE 1995. NOT ALL SYSTEM DETAILS RELEASED.
RECOMMENDATION		
COLLINS SYSTEM		

Table 3-10. Navigation Candidates.

COMPONENT/FUNCTION	BENEFIT	DISADVANTAGE
IMU		
LASER FIBEROPTIC	LOW DRIFTING RATE. LOW POWER CONSUMPTION. GPS UPDATEABLE.	LIMITED OPERATIONAL HISTORIES. NOT AS ACCURATE AS GAS BEARING OR MECH.
GAS BEARING	GREATER OPERATIONAL HISTORY. MORE ACCURATE THAN LASER OR FIBER OPTIC.	HIGHER POWER CONSUMPTION. COMPLEX. HIGH MAINTENANCE COSTS.
MECHANICAL	HIGHLY ACCURATE	HIGHER POWER CONSUMPTION. OLD. HIGH MAINTENANCE COSTS.
RECOMMENDATION		
LASER IMU		

gyro (RLG)/accelerometer system. A simple horizon scanner can provide backup for enhanced reliability. A qualitative assessment of the navigation and attitude candidate options is shown in Tables 3-10 and 3-11, respectively.

Atmospheric Flight and Landing. The atmospheric flight and landing systems will be based primarily upon a combination of differential GPS and a microwave landing system (MLS). Recent tests by Honeywell with NASA Langley have revealed differential GPS autolandings consistently within the accuracy of the microwave landing systems. This method should provide a low cost core technique for AMLS landings. A qualitative assessment of the atmospheric flight and landing candidate options is shown in Table 3-12.

Vehicle Instrumentation. The total vehicle instrumentation including the autonomic health monitoring system cannot be determined yet, since the total vehicle subsystems require detailed definition prior to the selection of the health and performance monitoring system. However, the ARINC specification for the SAAB 2000 aircraft will be an initial guideline for the system, see Table 3-13. Considerable progress and application has been achieved with health monitoring of contemporary aircraft. Rockwell-Collins and Boeing are jointly developing health monitoring hardware and software which will be directly applicable to the AMLS. This will result in significant AMLS program cost savings.

The recommended avionics system is a fully integrated spacecraft/-aircraft system. Easy-to-use, built-in diagnostics dynamically report the system operating status. This simplifies system maintenance and minimizes use of carry-on test equipment. The avionics system contains enhanced versions of contemporary avionics and also features an integrated avionics processor assembly (IAPS), a Mode-S transponder, and advanced

Table 3-11. Attitude Candidates.

COMPONENT/FUNCTION	BENEFIT	DISADVANTAGE
GPS RECEIVER(S)	HAS MULTIPLE USE	LIMITED OPS HISTORY
STAR TRACKER/COAS	PROVEN TECHNOLOGY	HIGH MAINTENANCE COSTS. COMPLICATED. EXPENSIVE.
HORIZON SCANNER	SIMPLER DEVICE THAN STAR TRACKER. CAPABLE OF PROVIDING ACCEPTABLE ACCURACY FOR ATTITUDE REFERENCE.	LIMITED OPS HISTORY
RECOMMENDATION		
GPS RECEIVER WITH HORIZON SCANNER BACKUP		

electronic flight instrumentation system (EFIS) as commonly employed by the latest commercial aircraft. In addition to the IAPS typical commercial aircraft contain at least the following subsystems:

- Instrument Display System
- Attitude Heading System
- Flight Management System
- Weather Radar System
- Air Data System
- Flight Control system
- Radio Sensor System
- Aircraft Data Acquisition System

Cockpit Design. The 4-tube system is a symmetrical configuration. A Primary Flight Display (PFD) and Electronic Flight Display are on the pilot side of the instrument panel; a Navigation Display and a Multifunction Display are on the copilot side of the panel. This system features PFD backup and radar displays for both pilot and copilot Options include VNAV, dual ADF, dual VLF, dual Flight Management Systems, a second Multifunction Display (installed instead of a Navigation Display on the pilot side), and turbulence detecting radar.

Table 3-12. Atmospheric Flight and Landing Candidates.

COMPONENT/FUNCTION	BENEFIT	DISADVANTAGE
MICROWAVE LANDING SYSTEM	PROVEN TECHNOLOGY. PROPOSED FOR EXISTING ILS REPLACEMENT.	REQUIRES GROUND STATION AT PRIMARY SITES
DIFFERENTIAL GPS	LOW COST. WORLD WIDE LANDING CAPABILITY	REQUIRES DIFFERENTIAL GPS AT EACH AIRPORT
VORTAC/ILS	LAND AT ANY COMMERCIAL OR MILITARY RUNWAY. PROVEN TECHNOLOGY.	REQUIRES ADDITIONAL EQUIPMENT ON BOARD
RADAR ALTIMETER	PROVIDES LOW ALTITUDE TERRAIN-TRACKING AND ALTITUDE SENSING.	REQUIRES ADDITIONAL EQUIPMENT
PITOT STATIC LASER AIR DATA SYSTEM	ACCURATE ALTITUDE AND SPEED INDICATION. NO PROBE.	LIMITED OPERATIONAL HISTORIES
RECOMMENDATION		
ALL OF ABOVE		

Communication and Tracking. The selection of communication and tracking components will be determined when the AMLS flight profiles and communication interfaces are defined. S-band will most probably be required, and GPS L-band, or UHF-VHF ATC comm and TACAN are still under consideration. A qualitative assessment of the potential candidates is shown in Table 3-14.

Table 3-13. Instrumentation Candidates.

COMPONENT/FUNCTION	BENEFIT	DISADVANTAGE
HEALTH MONITORING DIAGNOSTIC NETWORK	IMPROVED OPERATIONS. REDUCED LIFE CYCLE COSTS.	LIMITED OPERATIONAL HISTORIES
PERFORMANCE MONITORING	IMPROVED OPERATIONS/SAFETY. REDUCED LIFE CYCLE COSTS.	LIMITED OPERATIONAL HISTORIES
RECOMMENDATION		
PER ARINC SPEC FOR SAAB 2000		

Table 3-14. Communications and Tracking Candidates

COMPONENT/FUNCTION	BENEFIT	DISADVANTAGE
S-BAND	REDUCED COST, COMPLEXITY	LOW DATA RATE
L-BAND	REDUCED COST, COMPLEXITY	LOW DATA RATE
TDRSS	HIGH DATA RATES	COMPLEX. HIGH MAINTENANCE.
KU-BAND	ON-ORBIT RENDEZVOUS	COMPLEX. HIGH MAINTENANCE.
ATC COMM UHF/VHF	COMMONALITY WITH EXISTING COMMUNICATIONS SYSTEMS	LOW DATA RATE
RECOMMENDATION		
TBD COMBINATION OF ABOVE		

4.0 ACQUISITION PHASE DEFINITION

This section documents the definition of the acquisition phase; it presents planning data for program phases A, B, and C/D. These data have been developed based upon accomplishing the specific major activities related to design, development, production, test, verification, safety, reliability, quality assurance, and management and control for both hardware and software. The AMLS program master, the manufacturing flow and build plans and the work breakdown structure information matrices are part of this data and are presented in this report. Life cycle cost (LCC) data worksheets have been developed and are presented in (Reference 4-1).

4.1 MASTER DEVELOPMENT SCHEDULE

The preliminary master schedule developed for the AMLS reference concept defines the major program events and their interactions. These schedules will be expanded and improved during the trade study phase of the study to allow the development of subtiered schedules in other task areas.

The Preliminary Master Program Schedule, Figure 4-1, was developed for the reference concept to provide a set of key milestones for all elements, so that subschedules for each subtask can eventually be produced. Preliminary schedules are provided for all of the following activities:

- Engineering
- Facilities/Tooling
- System Development and Test
- Flight Operations Capability Development
- Production
- Orbiter Test
- Orbiter - Crew Module - Test
- Booster Test
- PCS Test

The LCC analyses and products reflect the milestones in this Preliminary Master Program Schedule. The functional task areas: Subsystem Design, Manufacturing and Verification, and Operations and Support will each be constrained by the milestone established by this schedule.

4.1.1 Program Milestones.

The Preliminary Master Program Schedule was driven by the assumption that the Phase C/D ATP would occur at the beginning of fiscal year 2000. This places the Phase A start at the beginning of fiscal year 1997, followed by Phase B start in the second quarter of fiscal year 1988. A summary of the Preliminary Master Program Master Schedule is presented in Figure 4-1. The Phase C/D activity will be discussed in more detail later.

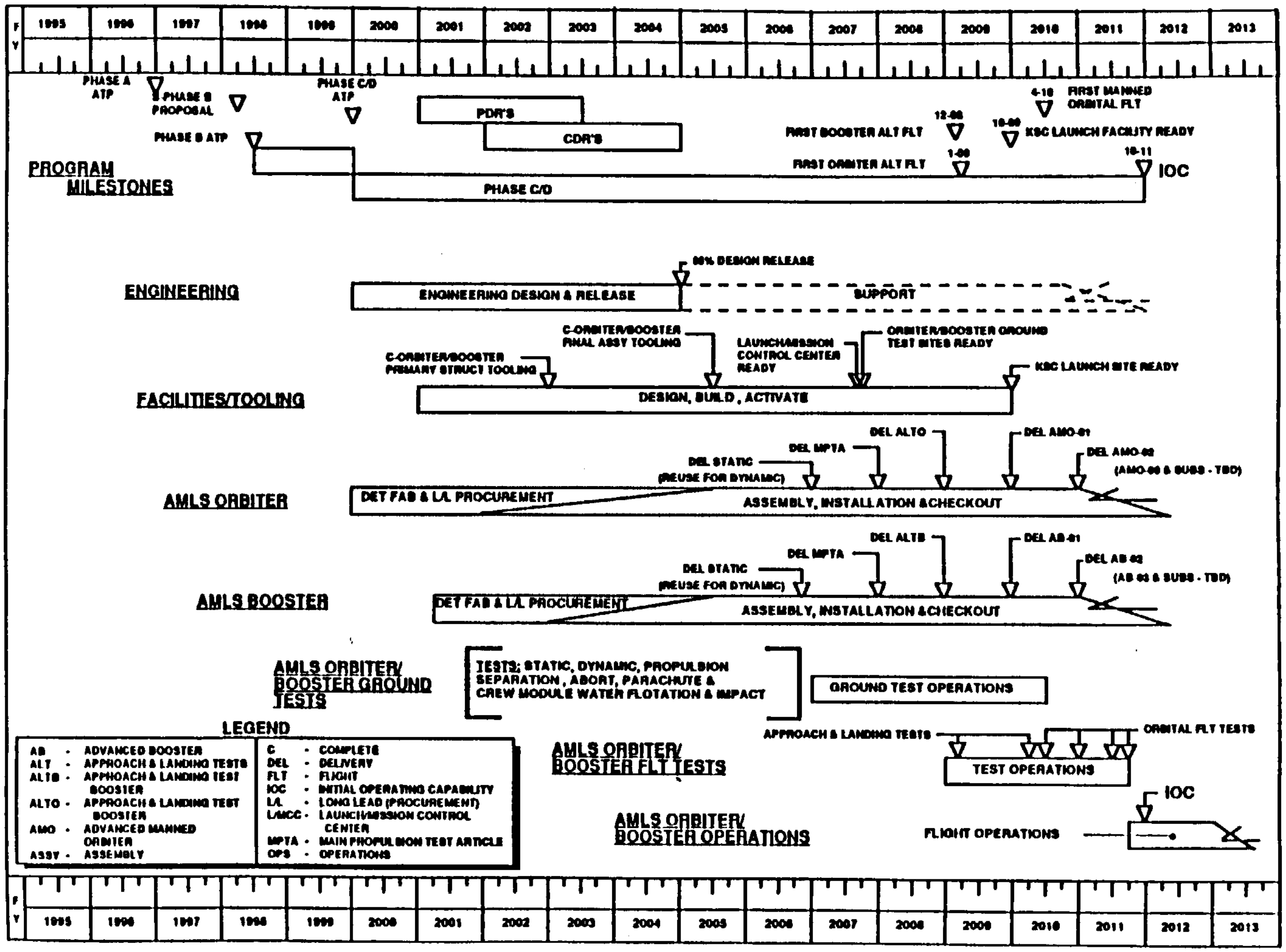


Figure 4-1. Summary Master Program Schedule.

4.1.2 Schedule Overview.

The following sections address the content of each page of the Preliminary Master Schedule, with a few words of clarification. See Figure 4-2.

Engineering. The engineering effort will support the PDR and CRD program reviews with 95% design release at the beginning of fiscal year 2005. Design engineering will support the production, qualification, verification and flight test validation activity.

Facilities/Tooling. The majority of new facilities are at the launch site and will be on line to support facility checkout and the orbital flight test programs. The production and operations tooling will be available to support all key milestones.

Systems Development and Test. All system development and test programs will be extensive, assuring a mature design for the operational phase of the AMLS program.

Flight Operations Capability Development The flight operations capabilities developments addresses all the mission support and crew training activity required to support the flight test and operational program.

Orbiter - Test. The orbiter test program consists of a structural test article for static and dynamic testing, main propulsion test article for orbiter and integrated propulsion testing with the booster, orbiter for the approach and landing tests at Edwards AFB in California, and the first flight vehicle to support the orbital flight test program.

Orbiter - Crew Module Test. The crew module test program consists of a structural test article for static and flotation testing, dynamic test article for vibro-acoustic and thermal vacuum testing and integration dynamic testing with the orbiter, and boiler plate flight test articles to support the parachute and escape system development testing. An flight test article will be produce for both the approach and landing, and orbital flight test program.

Booster - Test Articles. The booster test program consists of a structural test article for static and dynamic testing, main propulsion test article for booster and integrated propulsion testing with the orbiter, to support the approach and landing test at Edwards AFB and the first flight booster to support the orbital flight test program.

Payload Containment System - Test Article. The payload containment system has a unique structural test articles, in addition to test articles for the integrated orbiter dynamic tests, approach and landing and orbital flight test.

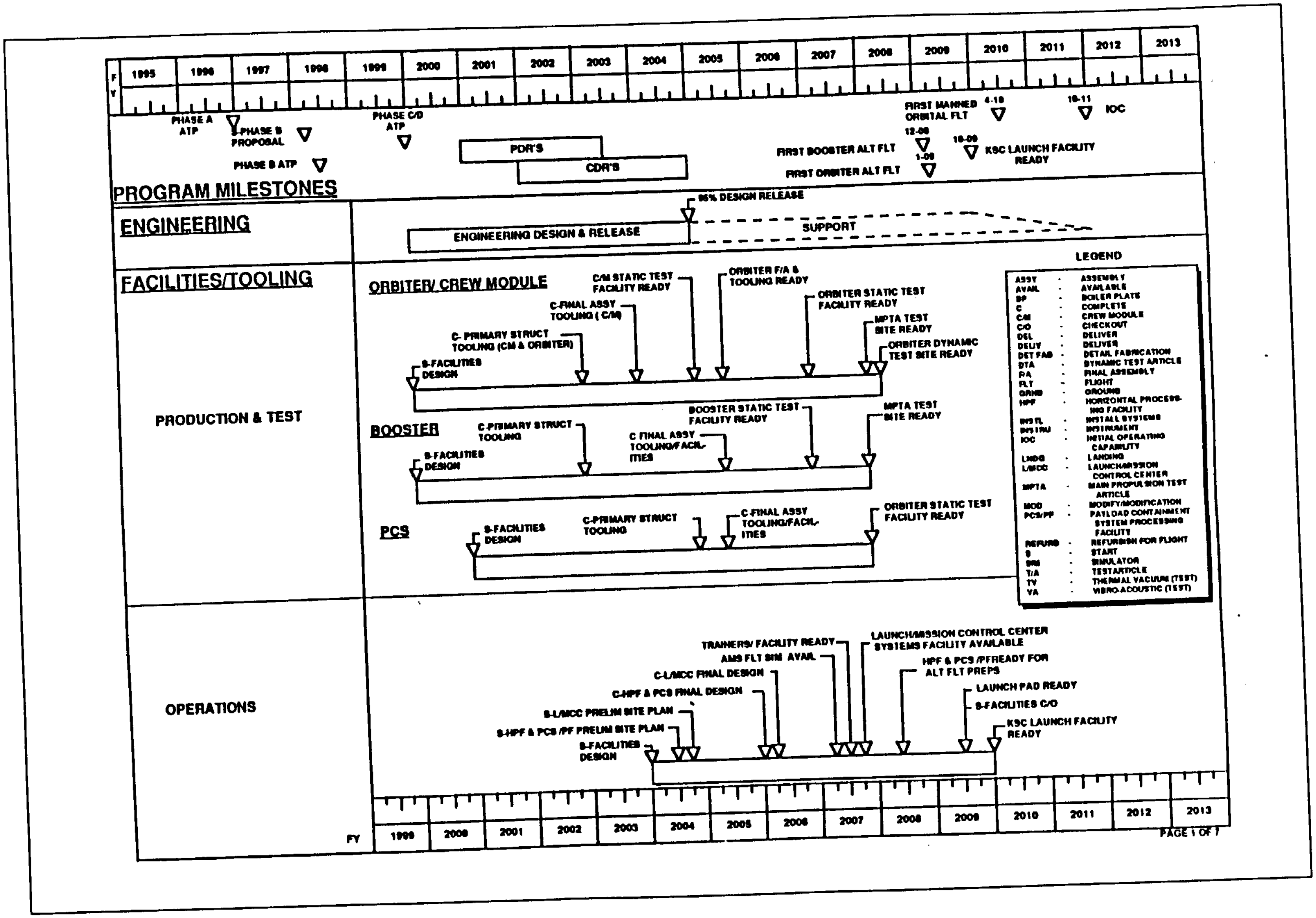


Figure 4-2a. Master Program Schedule.

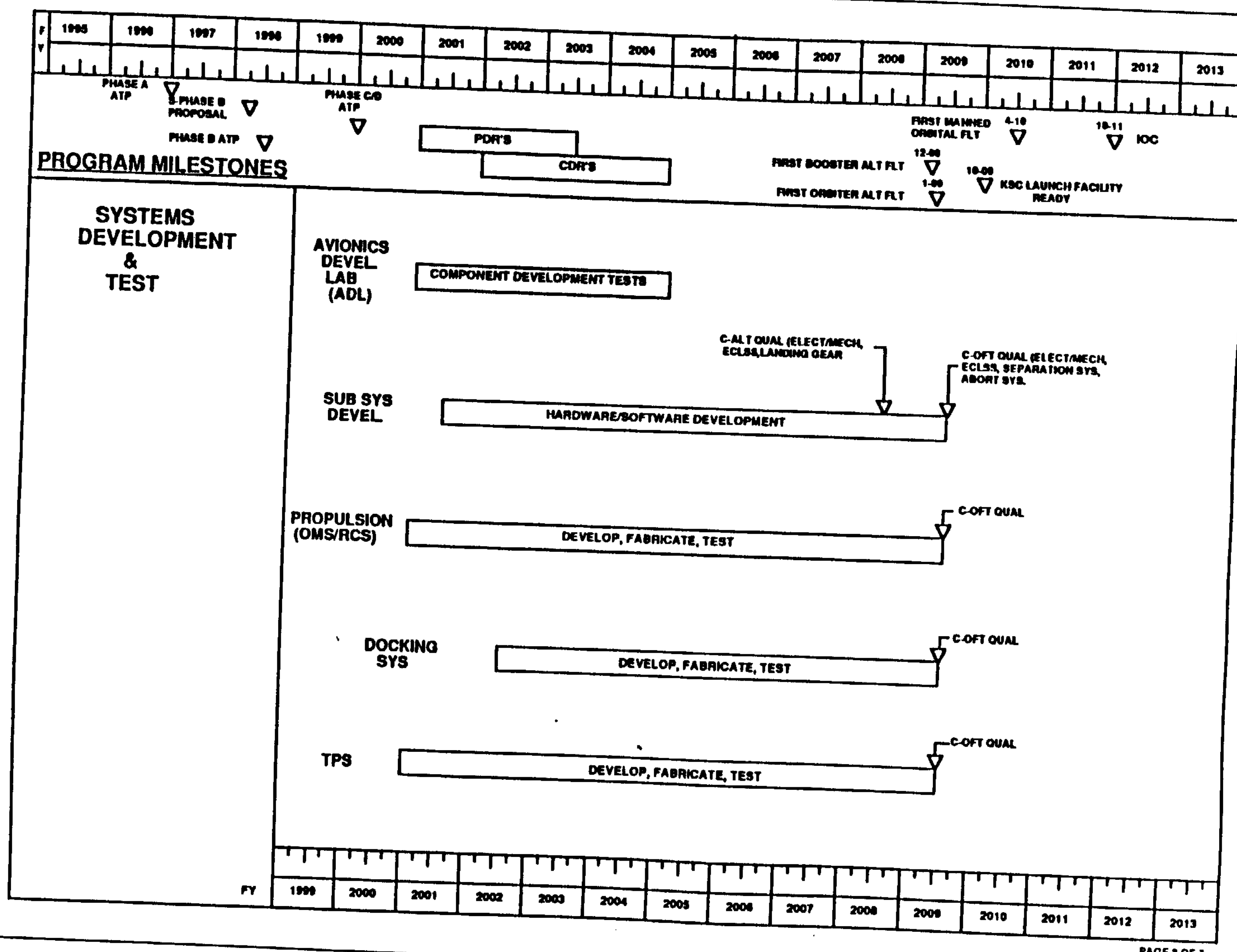


Figure 4-2b. Master Program Schedule (Continued).

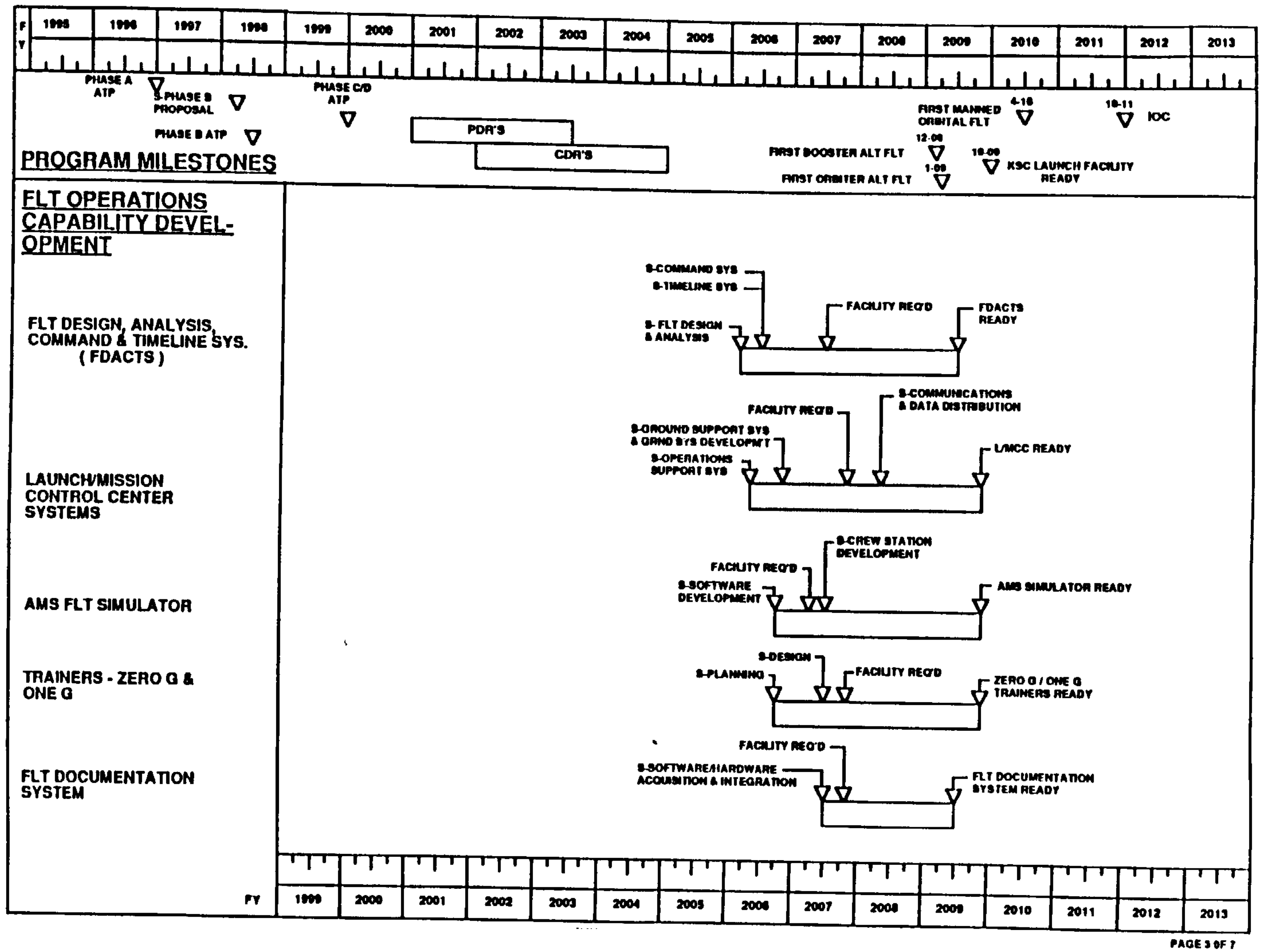


Figure 4-2c. Master Program Schedule (Continued).

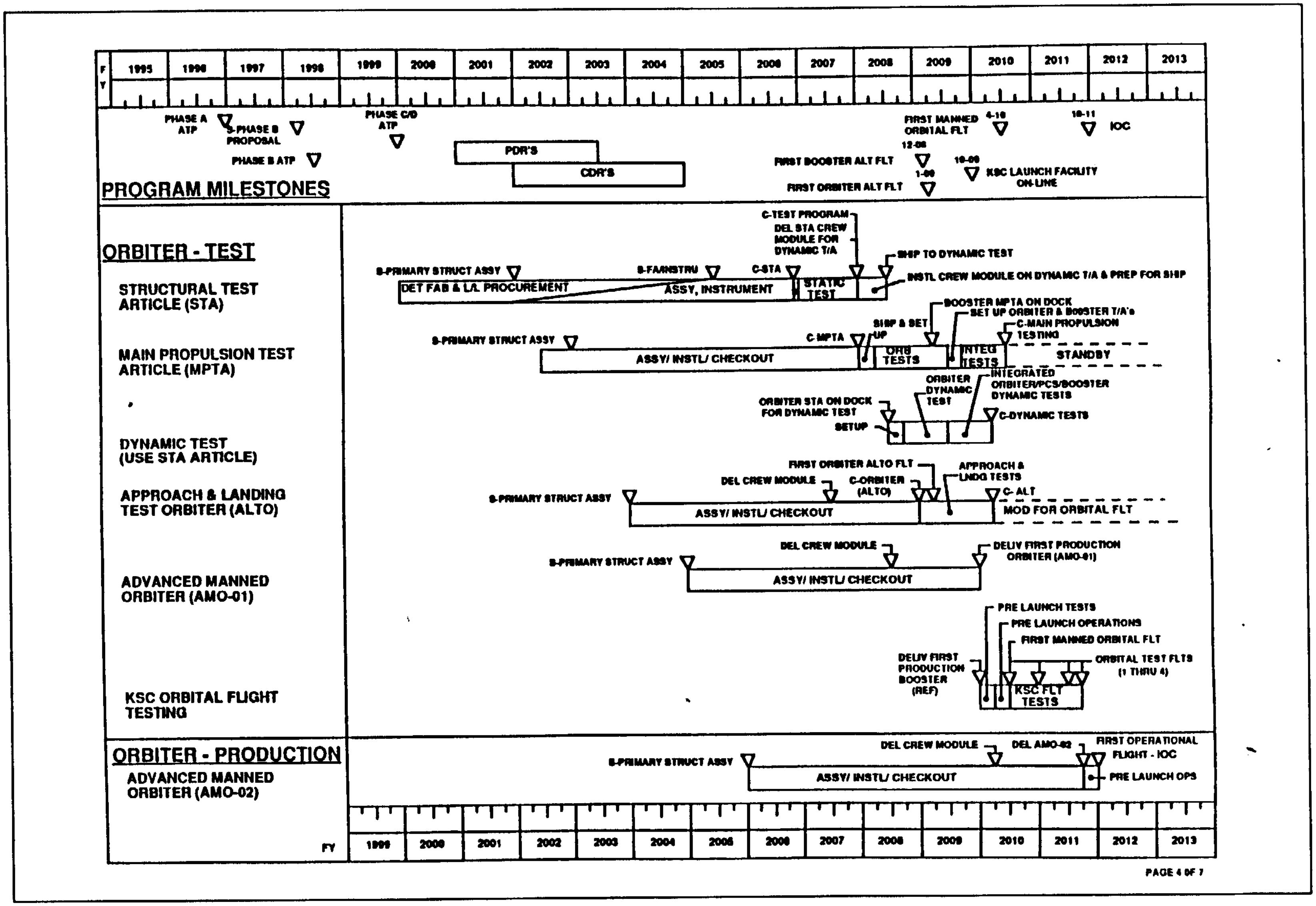


Figure 4-2d. Master Program Schedule (Continued).

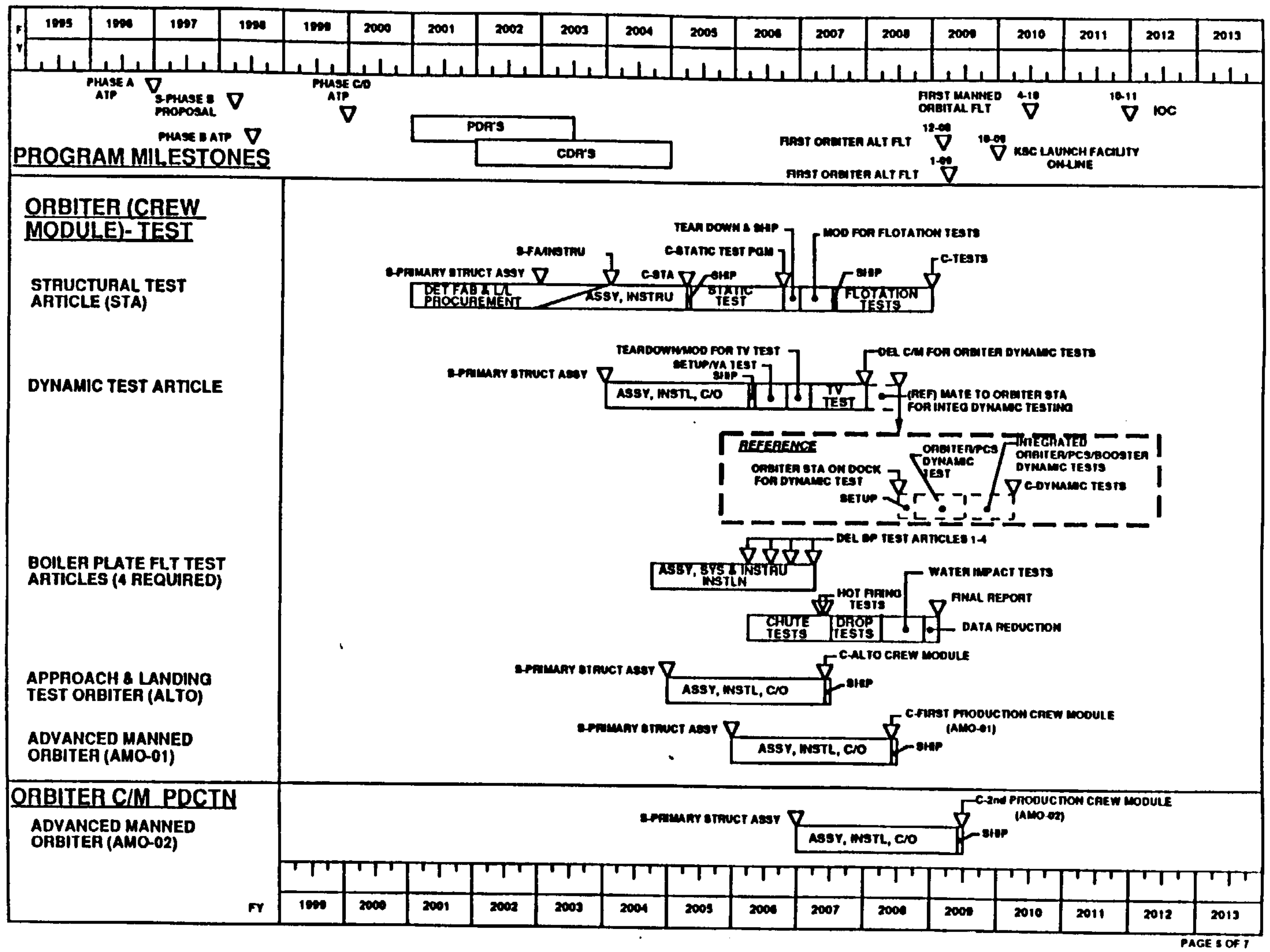


Figure 4-2e. Master Program Schedule (Continued).

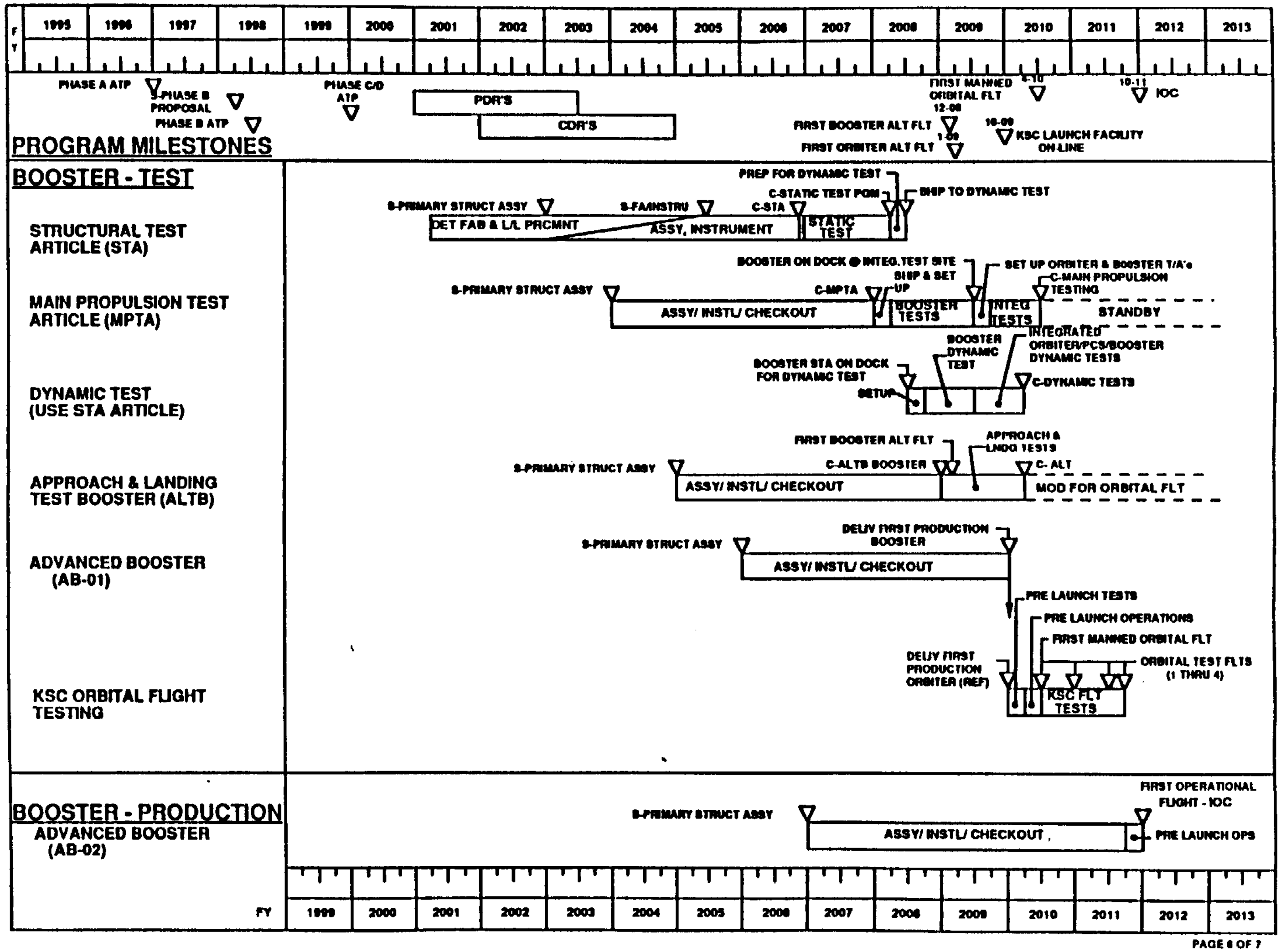


Figure 4-2f. Master Program Schedule (Continued).

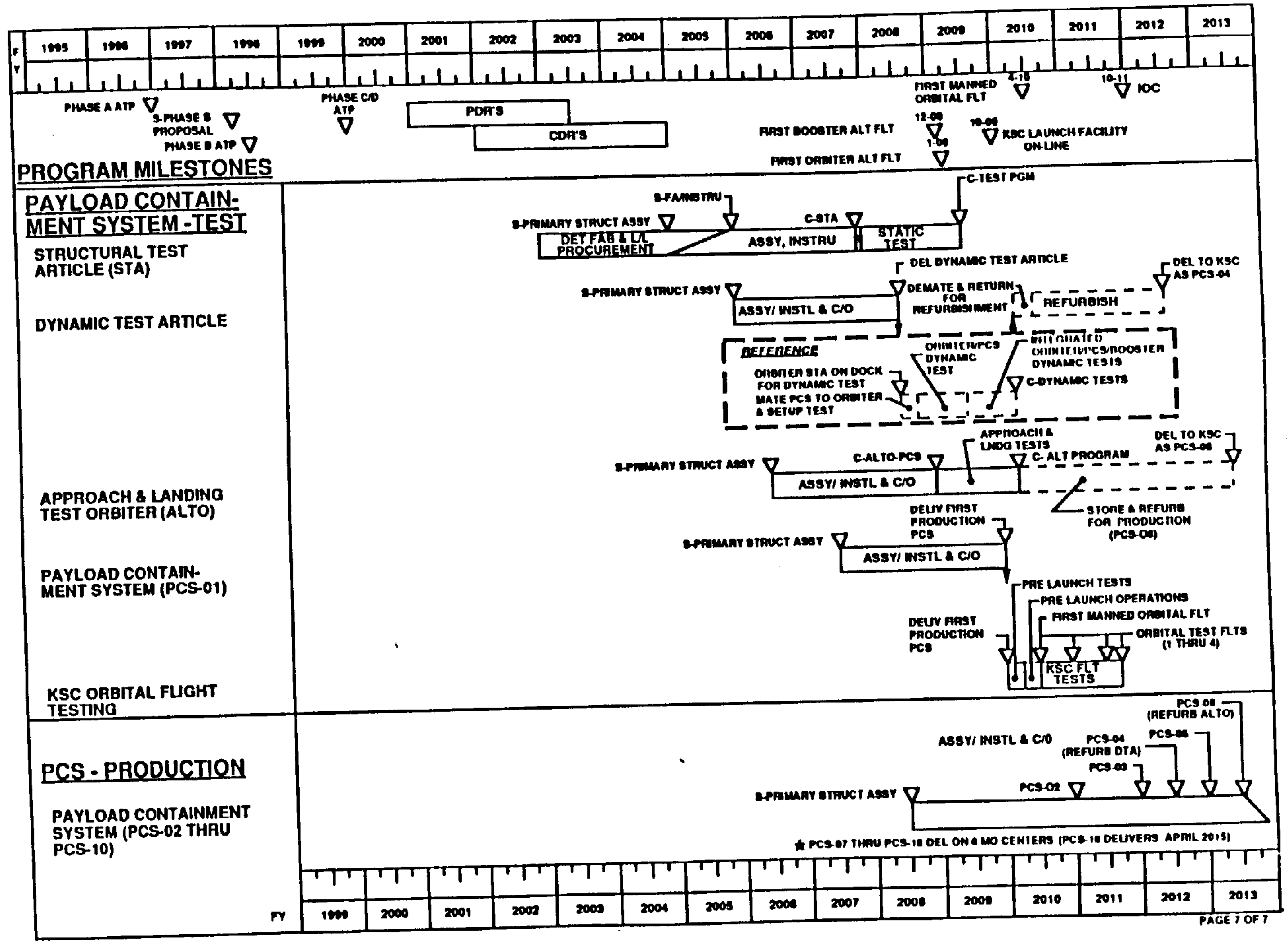


Figure 4-2g. Master Program Schedule (Concluded).

4.1.3 Flight Test Program.

The crew escape module, orbiter and booster vehicles and systems will be tested and verified during the following flight test program.

Parachute, Water Impact and LES Tests. The following qualification sequence for the AMLS crew escape module parachute system was obtained from Pioneer, the developer of the Shuttle orbiter drag chute. The parachute design is based on an existing design, sized to satisfy the AMLS requirements.

- Five bomb drops and 25 full three parachute tests are scheduled in the Orbiter (Crew Module) - Test schedules. The bomb drops would be with single parachutes and a dead weight equal to the design requirement. All parachute drop tests will be made from a large type air transport, like a C-5 or C-17.
- Twenty three of the three parachute tests will be drop tested with full up parachute system, mortar, and drogues. These tests will use one of four crew escape module boiler plate vehicles, which will have appropriate instrumentation for the drop tests. The boiler plate vehicles will be repaired as required to complete the parachute test program. To demonstrate robustness in the parachute system design, two chute drops, simulating a parachute failure, would be performed. Water impact tests will be performed in an appropriate water tank facility following the parachute drop tests.
- Two of the 25 three parachute tests will be two full up Launch Escape System tests, which will include an instrumented crew escape boiler plate vehicle and simulated front end of the AMLS orbiter, SRM's and parachutes and their systems.
- The crew escape boiler plate test vehicles will be available to perform other tests and fit checks as they become defined during follow-on phases of the AMLS study.

Approach and Landing Test (ALT). The orbiter and booster ALT programs validates the following AMLS system capabilities in a very controlled environment.

- Autoland Performance
- Landing Gear and Brake Performance
- Low Speed Aerodynamic Control Authority
- Cross Wind Landing Sensitivity
- G. Envelope Sensitivity
- Maximum Weight Vehicle Performance
- Final Approach Energy Management

There are three proposed ALT flights for both the orbiter and booster. Both the orbiter and booster ALT vehicles will be modified to orbital flight configuration, following the ALT flights.

Orbital Flight Test (OFT). The OFT program of the AMLS system verifies it is operational by validating the following analytical models developed to describe flight performance and environment:

- Aerodynamics
- Aerothermal
- Thermal - TPS/TCS
- Vibration/Acoustics *
- Loads *
- Venting

Those models marked with an "*" are limits the vehicle cannot exceed in flight since they have been verified by ground testing. The OFT program also establishes crew confidence in the AMLS flight worthiness design, operations, performance and handling quality.

The test results from each flight may result in changes: to the control loop lead, lag or gain: to follow-on fight test requirements: or operational flight limits. Final test results could also affect the subsystem design, like supplemental or reduced TPS requirements in local areas.

4.2 PRODUCTION

Manufacturing and system validation plans identify the production requirements, time lines (critical paths), issues/risks, facilities (requirements and recommendations), major equipment (including engine test stands, mock ups, test beds, iron birds, and simulations laboratories), testing and test articles, and integration approaches for the AMLS.

AMLS reference system manufacturing flow and build plans (MFBP) have been developed. These plans have been developed based upon the study ground rules (Reference 4-7), the technology development plan (References 4-2 & 4-8), the acquisition plan (Reference 4-8), operations support analysis (References 4-5 & 4-8), hardware/software design descriptions (Reference 4-9). The MFBP's display key fabrication sequences of the AMLS reference system. Accompanying detail narrative descriptions are provided below.

4.2.1 Acquisition Phase.

The AMLS objective is to design a safe, durable, low life-cycle-cost vehicle. Obtaining this objective starts by emphasizing producibility and maintainability in the preliminary design concepts. If it's designed and built correctly, it should be affordable. The design will be driven by operations and maintainability requirements and assured by an integrated system engineering, a total quality management (TQM) (Reference 4-3) approach and the USAF, R&M 2000 Process (Reference 4-4).

The first efforts associated with the development of our operations concept were to develop a series of functional flow block diagrams (FFBD's) that would capture the operational functions associated with the AMLS. The addition of the DDT&E blocks associated with "capabilities development" and operational flight test (OFT) verification provided the important links to the pre-production and operational periods that are necessary ingredients in our "design for operations" philosophy. Operations lower level flows are found in Reference 4-5.

AMLS program management has placed operations, maintainability and producibility in priority position of importance. This system will be producible within the boundaries of being first maintainable and operable. The key word is "<u>access</u>"! See Figure 4-3. The best examples of this are: the exterior access to systems through panels and on doors; and the manufacturing access openings in the crew escape module and the forward payload containment system section.

- Removable panels provide exterior access to systems and systems mounted on doors, opening to the vehicles exterior, provide access during manufacturing and during operations.

- Manufacturing access openings in the crew escape module and the forward PCS section and the will provide significant intangible benefits to the AMLS Program, as a similar access opening in the Space Shuttle Orbiter crew module. Additional benefits can be derived through the mechanical closure/opening, if and when it would be required to disassemble the transfer tunnel from the crew escape module. Improved manufacturability

- Fabrication of all AMLS vehicles and test articles in one production run is cost-effective for the program, since each Shuttle Orbiter was built with a personnel turnover rate of 70 percent. Continuous build will require only one facility and tooling setup, a minimum amount of retraining, and a one-time procurement of items including those with long lead times. Early planning will assure the operational spares requirements are included in the production order. The cumulative results of these actions will result in a cost effective manufacturing program and would support DRM-1 requirements (Reference 4-7).

- Fast turn around requires accessibility. To comply with that requirement, most avionic systems and other systems historically requiring operations attention are located on the exterior crew cabin structure, within accessible exterior compartments. In addition to accessibility, the systems will use mature, state-of-the-art techniques, including self-test.

- The electric system is direct current, thus simplifying or eliminating heat-producing conversion devices. The actuation systems are electro-mechanical, avoiding APU/hydraulic fluid problems.

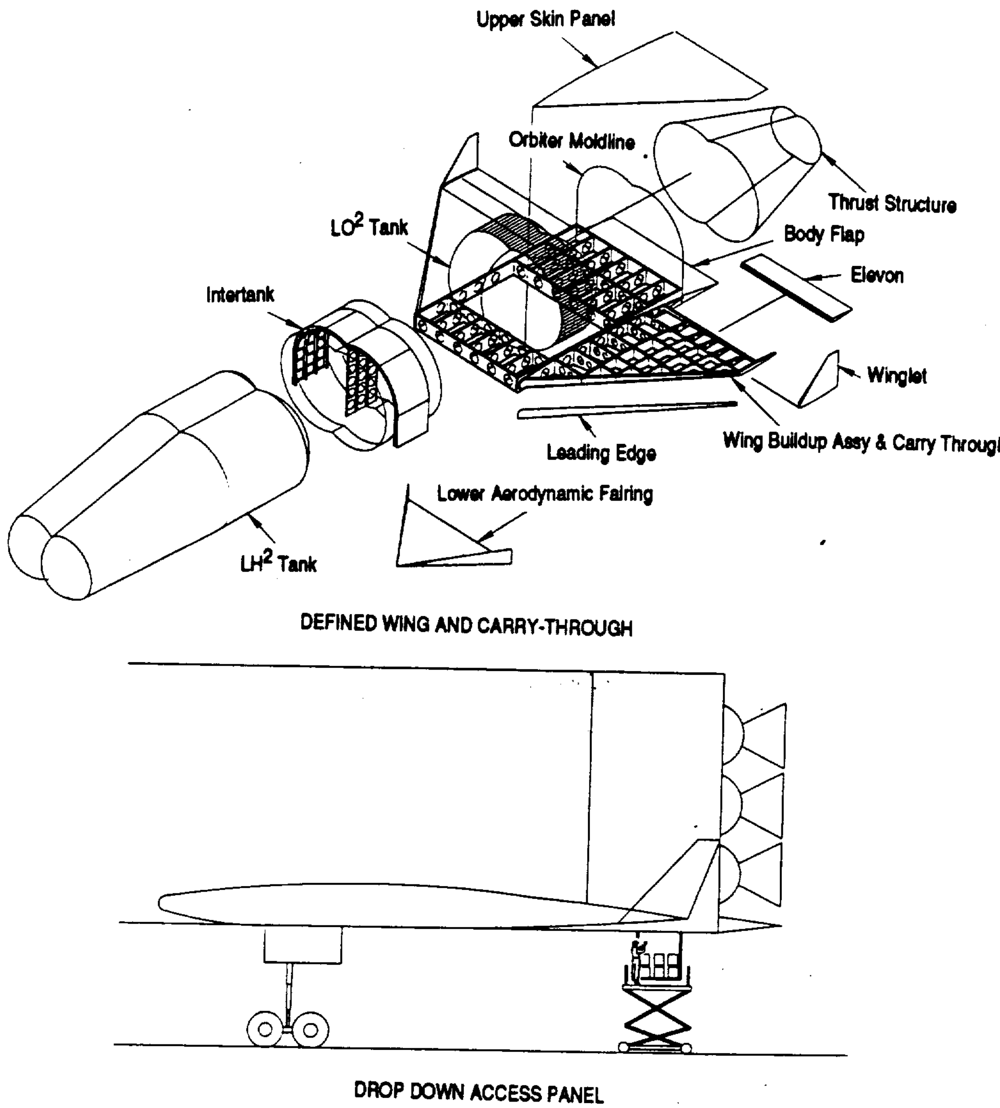


Figure 4-3. Producibility Influence On Design.

4.2.2 Manufacturing Flow and Build Concept - Booster.

The Booster fabrication (see the manufacturing flow and build plan (MFBP) consists of the:

Wing Group

- *Wings.* The wing body is fabricated of graphite polymide (Gr Pi) skins (box beam construction) with solid stiffened spars and ribs. The spars are solid laminates with stiffeners. They are layed-up and cured in an autoclave. The ribs are open truss plates made of Gr Pi laminates. A root rib provides support for the forward spar and for the vertical link attachment to the LH_2 tank. There are two main spars which carry the loads to the rigid attachment at the aft structure. The solid edges of the honeycomb sandwich skins are mechanically fastened to the internal structure. The leading edges are fabricated of titanium stiffened sheet in sections and are mechanically fastened to the wing front spar. The control surfaces consist of a box beam construction and are Gr Pi honeycomb sandwich panels, with solid stiffened spars and ribs. They are hinged to the rear spar. Electrical actuators are used. The personnel access cover panels are Aluminum-Lithium (Al-Li) panels machined, trimmed to size and mechanically fastened. Access holes in the upper surfaces of the wings provide access to the interior for manual or robotic assembly and inspection. The main landing gear supports are truss beams that are part of the Gr Pi wing box beams.

- *Wing Carry-Through* The wing carry-through consists of Gr Pi honeycomb skins with solid stiffened spars and ribs, formed into the wing box/transition skirt structure with Al-Li integrally machined, removeable panels and no insulation.

- *Wing-Body Fairing.* The wing-body fairing is constructed of light weight Gr Pi, layed-up, pressed and mechanically fastened. Expansion joints provided by oversize fastener holes permit relative thermal expansion between the wing and the tank.

- *Tip Fins.* The tip fins consist of a Gr Pi box beam, layed-up and pressed, honeycomb sandwich skins, solid stiffened spars and ribs, graphite bismaleimide moveable surfaces, full depth honeycomb core with no TPS, the leading edges are titanium, conventional aircraft construction. The tip fins are attached to the wing structure and movable control surfaces are attached at two hinges. Electrical actuators are attached to the moveable surfaces. Control wires are routed along the wing trailing edges.

Body Group

- *Nose Section.* The nose cap consists of a titanium "beanie" that covers the external foam insulation and Al-Li support structure. The assembly is mechanically attached to the tank forward extrusions. Assembly requires drill plates/holding and handling fixtures.

- *Intertank Section.* The intertank section is constructed of Al-Li panels, mechanically fastened to internal frames and stiffeners. It has external foam insulation, large personnel access panels on both sides and hardpoints for maintenance hardware attachment. The internal frames and stiffeners are machined and mechanically attached. The access panels are of cabinet opening type and contain door mounted components for easy interior access and maintenance. The nose landing gear supports are fabricated of aluminum-lithium alloy frames and stiffeners. They are mechanically fastened to the lower intertank structure.

- *Aft Structure.* The aft structure is Al-Li structure, mechanically fastened to the aft LH_2 tank skirt. It includes the wing carry-through and ties the wing to the body. The upper part of the aft structure includes the orbiter interface fittings. The aft structure also includes fixed frames that support removable engine fairing panels.

- *Engine Fairing Panels.* The removable engine fairing panels are made of light weight Gr Pi material. The panel assemblies are layed up and autoclave cured in a one-piece assembly. They are then trimmed, drilled and mechanically fastened to the aft structure frames using quick release high shear fasteners.

- *Main Propulsion Thrust Structure.* The MP thrust structure consists of an Silicon Carbide-Aluminum (SiC/Al) shell. Heavy SiC/AL longerons, mechanically attached, stiffen the shell structure. The engine interface ring is forged, machined aluminum.

- *Body Flap.* The body flap is composed of laminated graphite polymide box beams and spars. The skins are honeycomb sandwich panels. The body flap is hinged to the aft structure and driven by electrical actuators.

- *Base Heat Shield.* The base heat shield has solid stringers and spars and is covered with machined Gr Pi honeycomb sandwich skins, mechanically fastened. Insulation is attached to the skin panels.

- *Orbiter Interface Structure.* The Orbiter interface structure (to separation) consists of a 2 point attachment. The internal frames and longerons are machined and mechanically attached.

Propellant Tanks

- *Hydrogen Tank*. The hydrogen tank consists of Al-Li domes and barrel sections welded together. The domes are each made up of four identical quarters, made from Al-Li panels with internal frames and stiffeners. The welding process can be laser or high frequency (ultasonic) on automated, robotic fixtures and handling equipment. The domes are stretch formed, chem milled, and welded together on automatic fixtures. The two domes have personnel access panels that include line penetrations in the access panels for systems, inspections and maintenance. The barrel sections are shaped fusion welded assemblies made of Al-Li integrally stiffened skin panels, which have been machined from plate stock on numerically controlled (NC) mills. These skin panels include provisions for mounting support fittings for external propulsion line and cable trays. Tapped holes are provided with threaded inserts in the skin panels for installation and support fittings. Bosses are machined into the longitudinal stringers. The vortex baffle assembly is located at the siphon outlet having four identical baffle webs extruded and riveted with bracing rods to provide additional support to the assembly and screen assembly. Level sensors are installed in the forward and aft sections of the tank.

- *LH_2 Insulation.* The LH_2 insulation is exterior cryogenic SOFI/Rohacell foam with an ablative coating, that is to be developed.

- *Oxygen Tank.* The oxygen tank consists of Al-Li aft dome, ogive nose section, slosh baffle and cylindrical barrel section. Each is shaped, stretched formed, chem milled, and welded together in automatic fixtures. The dome is made up of four identical quarters and the ogive is made up of four identical quarters, made from Al-Li panels with internal frames and stiffeners, shaped and welded. The welding processes can be laser or high frequency (ulta sonic), on automatic, robotic fixtures and handling equipment. The aft dome has a personnel access panel that includes line penetrations in the access panel for systems, inspections and maintenance. The barrel section is a fusion welded assembly made of Al-Li integrally stiffened skin panels, which have been preformed and chem milled from plate stock. These skin panels include provisions for mounting support fittings for external propulsion line and cable trays. Tapped holes are provided with threaded inserts in the skin panels for installation and support fittings. Bosses are machined into the longitudinal stringers. The vortex baffle assembly is located at the siphon outlet having four identical baffle webs extruded and riveted with bracing rods to provide additional support to the assembly and screen assembly. Level sensors are installed in the forward and aft sections of the tank.

- *LO_2 Insulation.* The LO_2 Insulation is exterior cryogenic insulation, SOFI/Rohacell foam with an ablative coating, that is to be developed.

Landing Gear

- *Nose Gear.* The nose gear is a purchased component [DC 10-30 derivative, 2-wheel, steerable] - installed, integrated, and checked-out.

- *Main Gear*. he main landing gear are purchased components [Boeing 767 derivative two - 4 wheel truck] -installed, integrated, and checked-out.

Main Propulsion

- *Engines*. The engines are purchased components [SSME derivative] [five engines] - installed, integrated, and checked-out.

- *Engine Gimbal.* . The engine gimbals are purchased components - installed, integrated, and checked-out [1 gimbal and 2 actuators/engine]

- *Engine Mounted Heatshields*. The engine mounted heatshields are insulated blankets, mechanically fastened around the engines.

- *Pressurization System*. The pressurization system consists of purchased tanks, lines fabricated from stainless steel material, brazed/welded, with Al-Li support/brackets fabricated and mechanically fastened.

- *Lines and Manifolds*. The lines are fabricated from welded stainless steel tubing, the manifold components are purchased and the system is assembled, integrated and checked-out.

Propulsion, Rcs

- *Thrusters*. The thrusters are purchased components - installed, integrated, and checked-out. [7 front; 10 rear - Vernier]

- *Thruster Supports*. The thruster supports are purchased components - installed, integrated, and checked-out.

- *Pressurization System*. The pressurization system is manufactured from stainless steel tubing - installed, integrated, and checked-out.

- *Lines, Manifolds and Tanks*. The lines are manufactured from welded stainless steel tubing. The tanks and manifolds are purchased components. The components are - installed, integrated, and checked-out.

Prime Power

- *Fuel Cells*. The fuel cells are purchased components - installed, integrated, and checked-out.

- *Reactant Dewars*. The reactant dewars are purchased components - installed, integrated, and checked-out.

Electrical Conversion And Distribution

- *Power Conversion*. The power conversion components are purchased components - installed, integrated, and checked-out.

- *Electro-Mechanical Control Units*. The EM control units are purchased components - installed, integrated, and checked-out.

- *Cabling & Wiring*. Avionics power; actuator power and other systems power - The cabling and wiring are manufactured components - installed, integrated, and checked-out.

Actuators

- *Elevons: Tip Fins: and Body Flap*. The EM actuators are purchased components - installed, integrated, and checked-out.

Avionics

- *Guidance, Navigation and Control: Health Monitoring: Communications and Tracking: Displays and Controls: Instrumentation System: and Data Processing*. The avionics hardware components are purchased components - installed, integrated, and checked-out.

- *Flight Software*. The flight software is developed, system integrated and checked-out.

Environmental Control

- *Thermal Control*. Thermal control is provided by using the main propulsion cryogens as a heat sink.

- *Tank Purge*. Helium is used to purge the tanks. It is held in liquid storage tanks [purchased components] that are mechanically fastened to the vehicles secondary structure. The lines are manufactured, the system integrated and checked-out.

Auxiliary Recovery Systems

- *Orbiter Separation*. The Orbiter separation includes explosive nuts [purchased components] that are mechanically attached then severed during the separation sequence. All separation debris is contained.

4.2.3 Manufacturing Flow and Build Concept - Orbiter.

The Orbiter fabrication (that includes the crew escape module and payload containment system).consists of the following elements:

Wing Group

- *Wings*. The wing body is constructed of titanium-aluminum (Ti-Al). It is in a box beam geometry with three spars. Two spars carry the wing bending through the aft fuselage. The forward spar is run through the intertank structure. The spars are Ti-Al sine wave and spars attached by welding them to the upper and lower flanges. The ribs are tubular trusses of Ti welded to Ti end fittings and mechanically attached to the spars and skin panels. Welding fixtures, holding fixtures, X-ray and dye penetrant and handling fixtures are required for fabrication and inspection. Secondary structure is fabricated, integrated and installed for internal lines and cable supports. Wing skins are Ti-Al stiffened skin panels, superplastically formed and mechanically attached to the internal structure. The leading edges are fabricated of Advanced Carbon-Carbon (ACC) in sections and are mechanically fastened to the wing front spar. The ACC components are purchased components, integrated and installed. The control surfaces consist of ACC components, hinged to the wing aft spar. The wing upper surfaces structure have no TPS, access doors fabricated of Ti-Al stiffened skin and provides access to the wing interior. The lower surfaces have durable, hard surface TPS tiles, mechanically attached. The main landing gear supports are Ti-Al construction, mechanically attached to the wing structure.

- *Wing Carry-Through*. The wing carry-through is a part of the aft structure connection. It ties the wing to the body. It is of Ti-Al which is mechanically attached to the Al-Li aft structure. Titanium thermal isolators attach the wing carry-through box beam to the Al-Li tank skirts.

- *Wing-Body Fairing*. The wing-body fairing is constructed of light weight Gr Pi, trimmed, layed-up on molds for contour, fabricated then mechanically fastened to the structure. Expansion joints provided by oversize fastener holes permit relative thermal expansion between the wing and the tank.

- *Tip Fins*. The tip fins consist of Ti-Al stiffened skin panels, spars and ribs, ACC leading edges, durable TPS and secondary structure for cables and wiring supports. Access fixtures, drill fixtures and lay up fixture are required to support construction. The tip fins are attached to the wing structure and ACC movable control surfaces are attached at two hinges. Electrical actuators are attached to the moveable surfaces. Control wires are routed along the wing trailing edges.

Body Group

- *Nose Section*. The nose structure is fabricated of Al-Li with mechanically attached frames and stringers. The aerodynamic nose cone is ACC mechanically fastened, similar to the space shuttle orbiter nose cone. The nose landing gear support consists of aluminum-lithium alloy frames and stiffeners.

- *Crew Cabin/Escape Module*. The crew cabin structure is a welded cylindrical shaped unit constructed of Al-Li super plastically formed extruded rings, longerons and stiffeners that are laser welded. The shape is supported by machined rings and longerons with stiffeners that are mechanically fastened. The crew module separation systems includes shape and linear charges with guillotines to sever the module from the tank structure. There are housings and thrust supports fabricated of AL-Li to contain the tractor rockets and support equipment required for escape. The crew module escape battery is a purchased component, located in the separations systems housing. The parachute system is located in the rear of the crew escape module, attached to the structure. The compartment contains a cartridge assembly for the drogue parachute and main parachutes with lanyards stowed in a laminated holding cabinet. Positive opening of the doors is assured through the use of explosive bolts. The design consists of standard aircraft construction.

- *Intertank Section*. The intertank section is a semi-monocoque structure, of Al-Li, with flanges at each end for joining the LO_2 and LH_2 tanks. Its primary function is to receive, distribute and transfer loads between the tanks. The use of the intertank makes it possible for the orbiter to have separate propellent tank bulkheads, thus avoiding the design complexity and added operational constraints associated with common bulkhead configurations. A filament wound thermoplastic stiffened shell with internal frames and externally bonded stiffeners are used for the TPS panels that are mechanically attached, to the lower surface only. There are large access doors provided on each side.

- *Aft Structure*. The aft adapter is Al-Li structure, mechanically fastened to the aft LO_2 tank skirt. The aft adapter provides the connection between the thrust structure and the LO_2 tank.

- *Engine Fairing*. The aft structure is made of light weight Gr Pi panels that are hinged, contain edge seals and have external AFRSI blankets for insulation. The Gr Pi material is sheared, layed-up on a splash mold, trimmed, drilled and mechanically fastened. It includes the wing carry-through and ties the wing to the body. The lower part of the aft structure includes the booster interface fittings constructed of Al-Li with machined spars and ribs, mechanically connected to the frames and shell structure. The upper part of the aft structure includes the aft attachment of the payload carrier.

- *Main Propulsion Thrust Structure*. The MP thrust structure consists of an Silicon Carbide-Aluminum (SiC/Al) lobed conical shell. The engine interface ring is forged, machined aluminum. There is no TPS.

- *Access Tunnel*. The access tunnel consists of formed Al-Li panels that are welded into a cylinder 7 foot in diameter with openings at the front and rear.

- *Base Heat Shield*. The base heat shield has solid stringers and spars and is covered with machined Gr Pi honeycomb sandwich skins, mechanically fastened. Insulation is attached to the skin panels.

- *Body Flap*. The body flap is an ACC assembly with Ti attachments. Its EM actuator is located inside the body aft structure.

- *Docking Mechanism*. The docking mechanism consists of the National Space Transportation System standard in bay device.

Propellant Tanks

- *Hydrogen Tank*. The hydrogen tank consists of:

    - *Forward domes*. The forward domes are made of Al-Li quarter sections. These are machined and welded to form ellipsoidal shells. The welding processes can be laser or high frequency (ulta sonic), on automatic, robotic fixtures and handling equipment. Al-Li sheet is formed and welded, with bosses and stiffeners to distribute loads.

- *Aft domes*. The aft domes are similarly constructed into quarter sections that are shaped, stretched formed, chem milled, and welded in/on a rotating weld fixture, using support holding fixtures. Penetrations to the interior of the tank, such as for fill/drain and purge/vent, are incorporated into the quarter section domes.

- *Lobed sections*. The tapered and cylindrical lobed sections consist of machined or extruded y-section longerons of Al-Li, used at the joint between the shell and the web, single curvature stiffened skins and a central web. External stiffeners are used on the lower part of the LH_2 tank. The upper portion of the LH_2 tank has internal stiffeners. The skins are welded to the supporting frames and stringers. Secondary structures and associated details are installed prior to final closeouts. Slosh baffles are machine fabricated and are mechanically and weld attached to support frames.

The hydrogen tank cabling, instrumentation and lightning protection are supported via secondary structure components. These items may be detail purchased or fabricated, then integrated during tank build up after initial welding. The internal frames and external stiffeners are Al-Li welded. Chemically milled weld lands are provided along the skin panel edges and ring frame junctures. Local weld lands are provided for the welding of fittings to support the LH_2 recirculation line, pressurization line and level sensors. Included in this fabrication are the use of handling, transportation, welding, X-ray, dye penetrant equipment, access stands and facilities.

- *LH_2 Insulation*. The LH_2 insulation is multi-layer cryogenic insulation (MLI) panels bonded to the structure interior. Gaps are sealed with thermoplastic tape using a heat gun or laser equipment. Formed foam blocks are used to insulate the internal frames, stiffeners, and webs. The foam blocks are covered with an impervious film on top and covering the foam block to MLI intersection to prevent LH_2 migration. These covered formed foam blocks are bonded over the internal frames, stiffeners, and webs.

- *Oxygen Tank*. The oxygen tank consists of Al-Li domes, slosh baffle, central web, and lobed cylindrical barrel section welded together. The welding processes can be laser or high frequency (ulta sonic), on automatic, robotic fixtures and handling equipment. Heavy cusp longerons are welded in at the top and bottom. The domes each are made up of four identical quarters, shaped, stretched formed, chem milled, and welded in automatic fixtures. The domes have personnel access panels that includes line penetrations in the access panels for systems, inspections and maintenance. The barrel section is a fusion welded assembly made of Al-Li integrally stiffened skin panels, which have been preformed and chem milled from plate stock. These skin panels include provisions for mounting support fittings for external propulsion line and cable trays. Tapped holes are provided with threaded inserts in the skin panels for installation support fittings. Bosses are machined into the longitudinal stringers. The vortex baffle assembly is locate at the siphon outlet having four identical baffle webs extruded and riveted with bracing rods to provide additional support to the assembly and screen assembly. Level sensors are installed in the forward and aft sections of the tank.

- *LO2 Insulation*. The LO_2 Insulation is multi-layer cryogenic insulation (MLI) panels bonded to the structure interior. Gaps are sealed with thermoplastic tape using a heat gun or laser equipment. Formed foam blocks are used to insulate the internal frames, stiffeners, and webs. The same impervious film used over the foam blocks in the LH_2 tank will be used in the LO_2 tank to prevent the LO_2 from reacting with the foam blocks.

Thermal Protection System

- *External*. The external insulation consists of durable, hard surface TPS tiles on the lower surface and blankets on the upper surface. The external tiles are mechanically attached to the vehicles skin. The nose and wing leading edges are ACC, mechanically attached. The upper body surfaces are covered with bonded flexible ceramic blankets - AFRSI/TABI bonded to the structure. There is no TPS on the wing upper surface.

Landing Gear

- *Nose Gear*. The nose gear is a purchased component [DC 10-30 derivative, 2-wheel, steerable] - installed/integrated/checked-out.

- *Main Gear*. The main landing gear are purchased components [Boeing 767 derivative, two 4-wheel trucks] -installed/integrated/checked-out.

Main Propulsion

- *Engines*. The engines are purchased components [SSME derivative] [five engines] - installed/integrated/checked-out.

- *Engine Gimbals*. The engine gimbals are purchased components - installed/integrated/checked-out [1 gimbal and 2 actuators/engine]

- *Engine Mounted Heatshields*. The engine mounted heatshields are insulated blankets, mechanically fastened around the engines.

- *Pressurization System*. The pressurization system consists of purchased tanks, lines fabricated from stainless steel material, brazed/welded, with Al-Li support/brackets fabricated and mechanically fastened.

- *Lines and Manifolds*. The lines are fabricated from welded stainless steel tubing, the manifold components are purchased and the system is assembled, integrated and checked-out.

Propulsion, RCS

- *Thrusters*. The thrusters are purchased components - installed, integrated, and checked-out. [front: 9 vernier; rear: 12 Vernier, 18 primary]

- *Thruster Supports.* The thruster supports are purchased components - installed, integrated, and checked-out.

- *Pressurization System*. The pressurization system is manufactured from stainless steel tubing - installed, integrated, and checked-out.

- *Lines, Manifolds and Tanks*. The lines are manufactured from stainless steel tubing. The tanks and manifolds are purchased components. The components are - installed, integrated, and checked-out.

Propulsion, OMS

- *Thrusters*. The thrusters [3] are purchased components - installed, integrated, and checked-out.

- *Thruster Supports*. The thruster supports are purchased components - installed, integrated, and checked-out.

- *Pressurization System*. The pressurization system is manufactured from stainless steel tubing - installed, integrated, and checked-out.

- *Lines, Manifolds and Tanks*. The lines are manufactured from stainless steel tubing. The tanks and manifolds are purchased components. The components are - installed, integrated, and checked-out.

Prime Power

- *Batteries*. The battery is a purchased component, installed, integrated and checked-out.

- *Fuel Cells.* The fuel cells [4] are purchased components - installed, integrated, and checked-out.

- *Reactant Dewars*. The reactant dewars are purchased components - installed, integrated, and checked-out.

Electrical Conversion And Distribution

- *Power Conversion*. The power conversion components are purchased components - installed, integrated, and checked-out.

- *Electro-Mechanical Control Units*. The EM control units are purchased components - installed, integrated, and checked-out.

- *Cabling & Wiring.* Avionics power; actuator power and other systems power - The cabling and wiring are manufactured components - installed, integrated, and checked-out.

Actuators

- *Elevons: Tip Fins: and Body Flap*. The actuators are purchased components - installed, integrated, and checked-out.

Avionics

- *Guidance, Navigation and Control: Health Monitoring: Communications and Tracking: Displays and Controls: Instrumentation System: and Data Processing.* The avionics hardware components are purchased components. installed, integrated, and checked-out.
- *Flight Software*. The flight software is developed, system integrated and checked-out.

Environmental Control

- *Personnel ECS.* Air & CO_2 Removal; Equipment Cooling; Heat Transfer Loop; Heat Rejection System (FES); and Radiators - The ECS hardware components are purchased components - installed, integrated, and checked-out.

- *Thermal Control*. Provided by using the main propulsion cryogens as a heat sink in conjunction with externally mounted radiators.

- *Tank Purge*. Helium is used to purge the tanks. It is held in liquid storage tanks [purchased components] that are mechanically fastened to the vehicles secondary structure. The lines are manufactured, the system integrated and checked-out.

Personnel Provisions

- *Galley: Personnel Hygiene: Trash: Storage: Seats: Sleep Stations: Fire Detection and Suppression: Medical Equipment: and Food and Potable Water*. Purchased and government furnished equipment - installed, integrated, and checked-out.

Auxiliary Recovery Systems

- *Personnel Rapid Egress*. TBD

Payload Containment System

- *Forward PCS Workstation*. The forward PCS workstation will form an integral part of the orbiter and will be constructed of Al-Li sheet, mechanically fastened to spars and stringers. The forward PCS workstation is a conical pressure vessel of Al-Li construction with stringers and stiffeners. It is permanently attached to the orbiter. It houses some consumables, crew storage, sleep station, galley and systems, air lock assembly and docking work station. The forward PCS assembly attaches to the tunnel assembly and the forward outer section has TPS for thermal protection.

- *Aft Payload Canister*. The aft payload canister is removable from the orbiter. The payload support compartment construction is of Al-Li sheets over stringers. Provisions for supports and brackets for additional support for the payload, such as, tanks, lines, wiring and instrumentation are provided. In addition, access panels and interconnect panels are provided. Critical structural provisions of the PCS include two ball-joint fittings on the aft structure and associated supporting internal structure. These are machined of Ti with Al-Li machined supporting structure and internal frames.

  The forward payload canister support is a hinged link which is mounted on a LH_2 tank frame. Included are thermal isolators for the forward support link. A retractable electrical/data interface plate will be fabricated of Al-Li. Laminated Gr Pi fairings will be provided to seal against pressure differentials. TPS blankets will be fabricated with attachment fairing connections. The payload bay is fabricated using the mid body space shuttle orbiter construction concepts of ribs, spars and stringers with Al-Li sheet paneling.

  Graphite epoxy doors for access/removal of payloads during flight are fabricated using standard manufacturing concepts. Doors are electro-mechanically operated. Wiring/cabling and provisions for pneumatic lines for payloads will be fabricated using brackets/standoffs and secondary structure.

- *PCS Mount Hard Points*. There are six PCS mount hard points for attachment of the PCS to the orbiter.

4.2.4 Manufacturing Master Schedule.

The Manufacturing Master Schedule, has been developed using program-level milestones. It references the program schedules in Section 4.1.1 of this report, which support system requirements and integrated task time estimates. The schedule provide optimum support for the manufacturing program in all areas, including engineering, facilities, material procurement, manpower loading and tooling, and application of comparative measurements of historical Space Shuttle performance.

System support hardware will be fabricated via a blended schedule to maintain systems used throughout the vehicle. All other schedule bars are major components and hardware groups of the overall vehicle and, as such, stand alone with their own flow plans. Final assembly and checkout will be the point in time when the major vehicle components are mated, allowing systems integration and subsequent testing. Flow plans may be established for each major component/hardware group shown on the master schedule, providing an orderly time phasing for Manufacturing production activities. The schedules serve as the basis for manpower loading, material need, and facility and equipment usage. Optimum control points will be established to provide performance controls, change control, and status information that will be measured against the master schedule.

4..3 TEST AND VERIFICATION

Manufacturing and fabrication of flight hardware includes the verification of system operation, both individually and integrated. The system will be validated during the operational phase of the contract. The following definitions are being used by the study:

- Verification: All tests (and/or checkout) performed prior to validation of the system
- Validation: Certification of the system performed during the operations phase of the contract (such as space vehicle flight readiness review sign-off or flight worthiness-aircraft certification)

4.3.1 Philosophy.

The testing philosophy is to achieve system validation without overkill. The aircraft industry approach to verification and validation has been reviewed and evaluated to determine the most efficient and effective manner of achieving validation.

Emphasis on development testing will provide assurance of a sound product and generate high confidence in a successful qualification test program. A robust development test followed by a high-fidelity integration test will lead to a flight worthy, low-risk system. The flight test segment will be planned to provide evidence that flight boundaries and requirements have been met. Guided by lessons learned, the testing concept developed here supports the basic philosophy of assuring a safe, durable, cost-effective AMLS.

4.3.2 Life Cycle Development..

Development test and evaluation (T&E) serves a number of useful functions. It will provide information to AMLS decision makers responsible for making cost and risk decisions which impact life cycle cost and reliability over the life of the system, such as early selection of system elements that will satisfy specification requirements, definition of subsystem element performance and compatibility with the evironments, and proof of interface compatibility between subsystems.. T&E will be conducted to demonstrate the feasibility of design approaches, to minimize risk, to identify design alternatives, to compare and analyze tradeoffs and to estimate operational effectiveness and suitability. As the AMLS undergoes design and development, the emphasis in testing will move gradually from development to operational T&E. The later phase will focus on questions of operational effectiveness, suitability and supportability. As noted, T&E is a process that will be continuous through the development and operational phases, A,B and C/D, (Figure 4-4).

Phase A, or Conceptual Exploration, is the time frame when the T&E Master Plan (TEMP) is conceived. The TEMP is the basic planning document for all T&E functions. The TEMP is the guiding manual for planning, reviewing and approving T&E programs and provides the basis and authority for all other detailed test related documents. It will identify all critical technical characteristics, operational issues and T&E schedules. The TEMP will be reviewed and updated as the program matures. Key topics contained in the TEMP are shown in Figure 4-5. In addition to development of the TEMP, development testing will begin during Phase A and continue into Phase B.

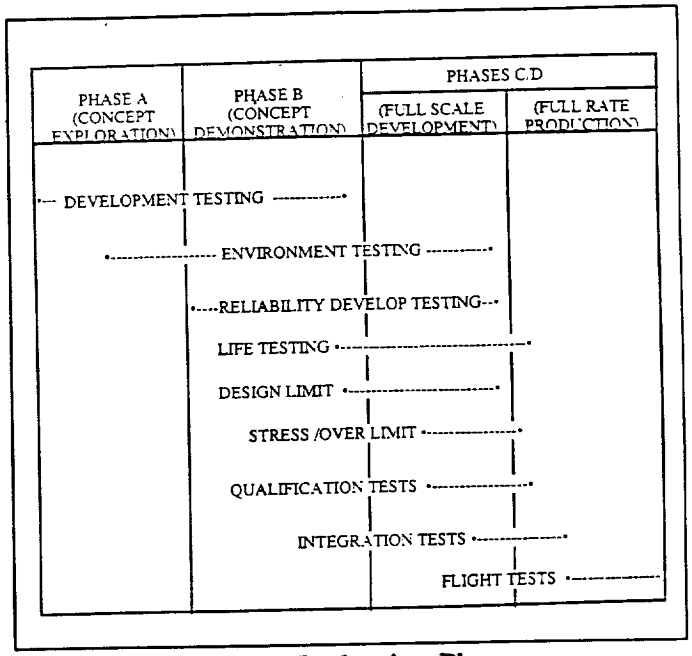


Figure 4-4. Test and Evaluation Phases.

4.3.3 Test Documentation and Certification.

Documentation. Test documentation is a major part of the test program and can be a significant contributor to test program cost and therefore must be efficiently managed. AMLS test documentation cost will be held to a minimum, consistent with good management practices. A detailed documentation water fall listing, in appropriate order, test documents from top to bottom has not as yet been developed; however, such a list is expected to contain the documents, or comparable ones, noted in Table 4-1, Test Documentation Tree. It is assumed that NASA will publish a master verification plan similar to the Shuttle's and it will guide, in part, test documentation orientation for AMLS. Though a formal document list has not be developed, a number of documents are planned starting with the TEMP.

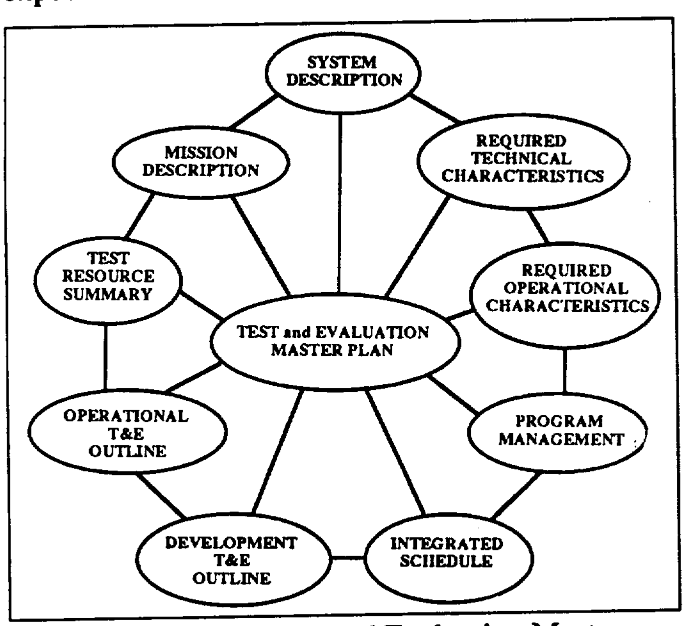


Figure 4-5. AMLS Test and Evaluation Master Plan.

Certification. Certification is the act of declaring that a subsystem, system and /or vehicle has satisfied all constraining requirements and is ready for the next major event. The certification process to be followed for the AMLS program is depicted in Figure 4-6.

Table 4-1. Test Documentation Tree.

MASTER VERIFICATION PLAN	
MIL-STD-1540B (USAF)	TEST REQUIREMENTS FOR SPACE VEHICLES
MIL-HDBK-340 (USAF)	APPLICATION GUIDELINES FOR MIL-STD-1540 TEST REQUIREMENTSFOR SPACE VEHICLES
ENVIRONMENTAL ACCEPTANCE TESTING	
	ENVIRONMENTAL REQUIREMENTS AND TEST CRITERIA
	DEVELOPMENT AND QUALIFICATION TEST REQUIREMENTS
SYSTEM AND SUBSYSTEM CERTIFICATION	
	CERTIFICATION REQUIREMENTS
	PROCUREMENT SPECIFICATIONS
	TEST PLANS
	TEST PROCEDURES
	TEST REPORTS
	ENGINEERING ANALYSIS REPORTS

4.3.4 Qualification Test Approach.

Qualification of a space transportation system requires both ground and flight testing and each plays a unique roll in the process of achieving flight certification. Design requirements of a space vehicle system are basically derived from the results of math and other technical models that were modeled from past experience, new techniques and mission requirements. Testing is the method used to verify that the models and the products generated from the model data satisfy requirements and depict the correct environment.

Ground testing is the primary means of verifying that the vehicle design satisfies the structural , dynamic

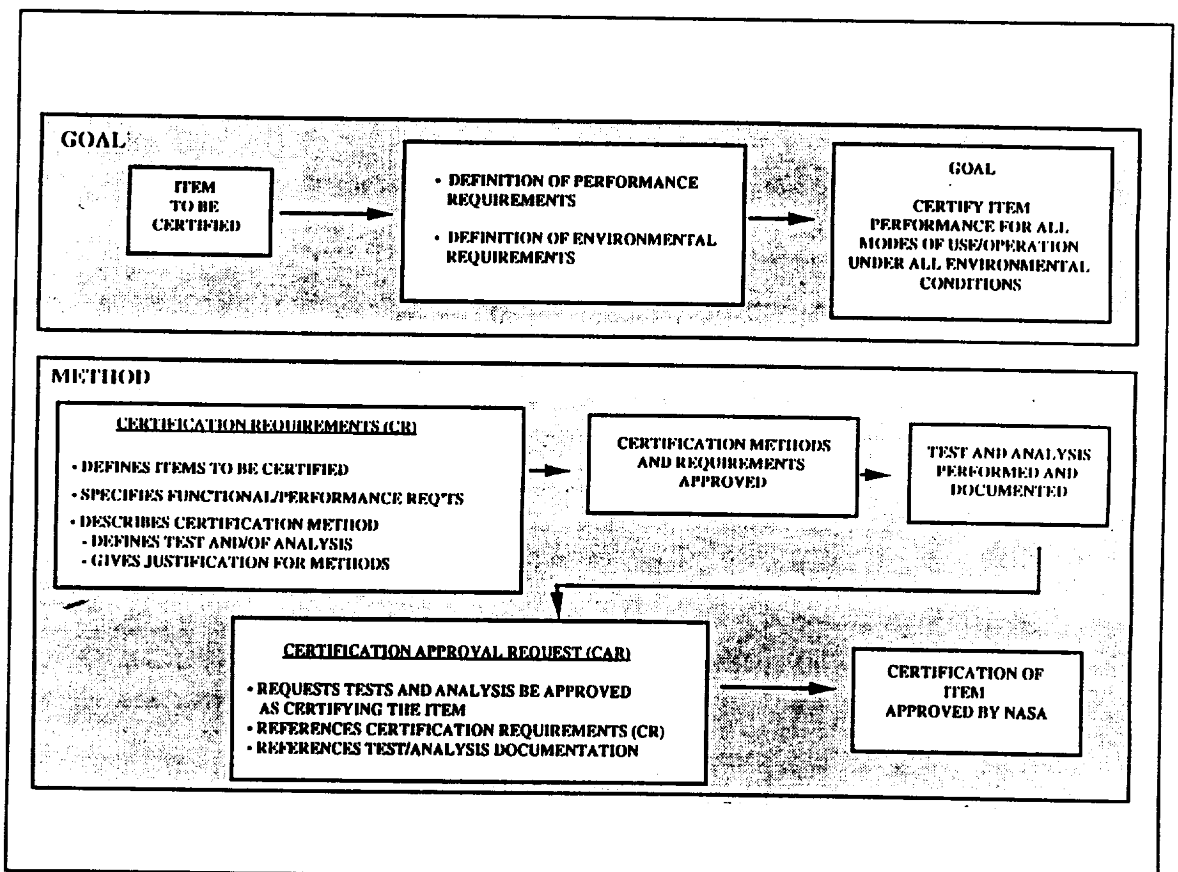


Figure 4-6. Certification Process.

and thermal requirements as defined by the models and wind tunnel tests. Ground testing is also the general format for verifying components, assemblies, subassemblies and integrated systems comply with stipulated requirements and performance parameters. It is generally impractical for a space vehicle to fly the boundaries of design during qualification testing so the models and other technical data used in the design of the vehicle are verified through flight testing. A simplified overview of the process that will be followed to achieve verification is illustrated in Figure 4-7. The verification plan sets the stage for verification and, ultimately, certification for operational flights.

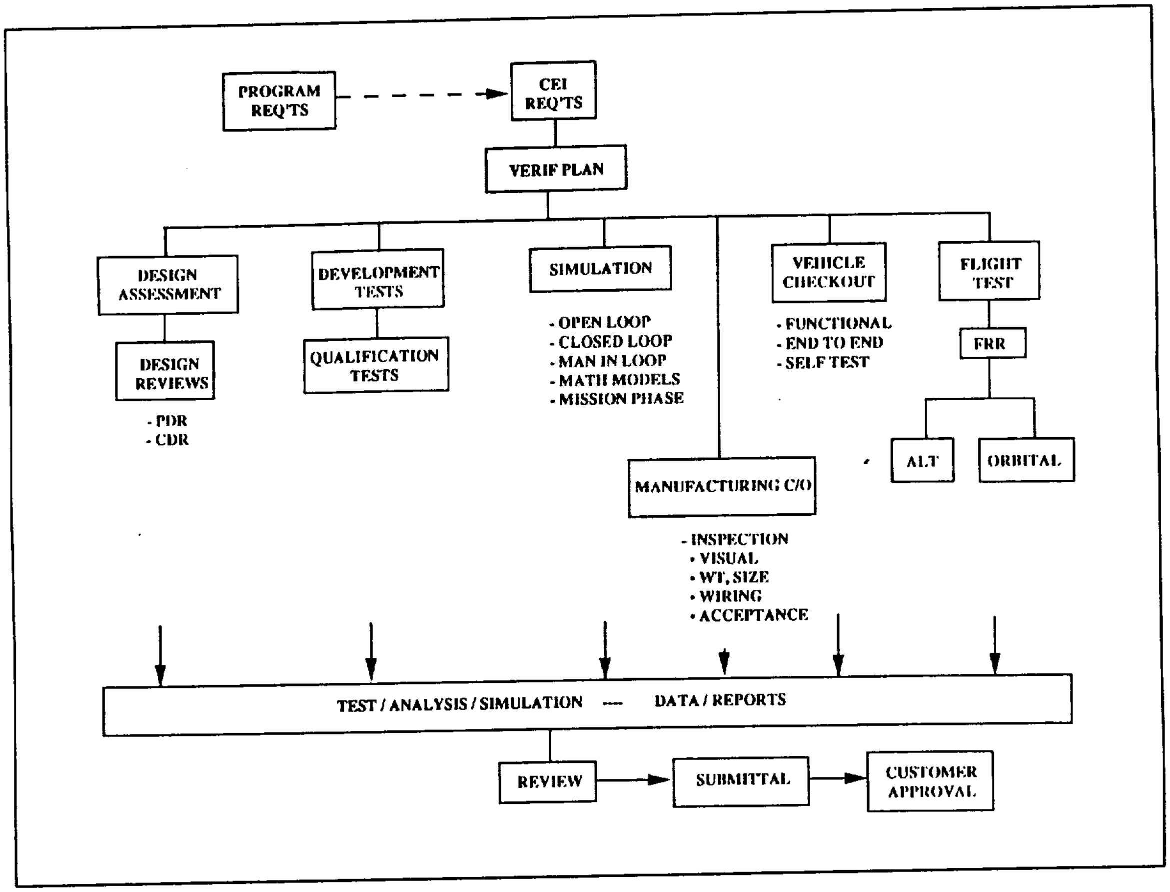


Figure 4-7. Verification Process.

<u>Ground Test Program</u>. Ground tests will expose AMLS equipment and structures to environments that are calculated to be at least equal to and in some cases substantially exceed the expected operational environment for marginal assessment. Exposure may be through similarity, analysis, demonstration and/or test. Similarity and/or analysis are the preferred methods from a cost and time standpoint and these methods will be used whenever the risk is consider acceptable. Candidates for acceptance through similarity /analysis are components previously employed in non critical space applications which have displayed a high reliability factor. The purpose of the ground test and its objectives for AMLS are defined in Table 4-2.

The flight hardware qualification test portion of the integrated test program will be structured to ensure that design performance can be realized under mission environments.

Table 4-2. Ground Test Program Objectives.

GROUND TESTING IS THE PRIMARY MEANS OF VERIFYING THAT THE VEHICLE DESIGN SATISFIES THE STRUCTURAL, DYNAMIC, THERMAL, AND FLIGHT REQUIRMENTS AS DEFINED BY MODELS AND WIND TUNNEL TESTS.

GROUND TESTING IS ALSO THE GENERAL FORMAT FOR VERIFYING COMPONENTS, ASSEMBLIES, SUBASSEMBLIES, AND INTEGRATED SYSTEMS COMPLIANCE WITH STIPULATED REQUIREMENTS AND PERFORMANCE.

OBJECTIVE: ASSURE THAT THE SYSTEM WILL MEET FLIGHT OBJECTIVES WHILE ACHIEVING AND MAINTAINING A LOW LIFE CYCLE COST PROFILE.

MAJOR TEST PARAMETERS WILL INCLUDE:

STRESS TEST THE STRUCTURE AND CREW MODULES AND ATTACHMENTS TO CALCULATED CRITERIA CONDITIONS INCLUDING HIGH Q, HIGH g'S, WATER IMPACT, THERMAL, VIBRATORY, AND LIFTOFF & LANDING CONDITIONS

STRESS TEST THE LANDING GEAR AND BRAKE SYSTEMS TO MAXIMUM LANDING LOADS WITH LIMIT CROSS WIND CONDITIONS

STRESS TEST CRITICAL AVIONICS, POWER, AND ECLSS SYSTEMS:
- OVER AND UNDER RATED POWER LEVELS
- INDUCED FAILURES
- ANOMALY SOFTWARE COMMANDS
- WORST CASE ENTRY CONDITIONS
- EXTENDED MISSION PROFILES

Figure 4-8 provides an outline for ground qualification of all flight hardware phased tó support the first test article. Subsequently, these test data will be supplemented with flight data from ALT and OFT flights as a means of certifying for AMLS operational use. The environments established for qualification will be tailored to each hardware item based upon individual sensitivity to the mission environmental conditions, flight criticality, safety, mission success considerations, ease of maintainability and historical experience.

Qualification requirements will encompass the environment associated with transportation, handling, ferry conditions as well as those associated with the mission. The general approach for the AMLS program will be to make ground conditions appropriate for the misśion profiles. Environmental qualification test requirements will be determined by comparing mission profile environments to the sensitivity of individual components. The decision will take into account the state-of-the-art (maturity) of the hardware and cost and risk. Mature commercial and military avionics considered applicable but sensitive to space environment will be modified and upgraded for AMLS application.

Qualification testing will require test specimens. A portion of these specimens will first be subjected to design performance limits under environments applied sequentially for design proof at the component level. Other specimens, as required, will be tested as an integral part of a subassembly, when practical, and exposed to single and combined environments to determine interface compatibility and verify operational life capability. The specific qualification

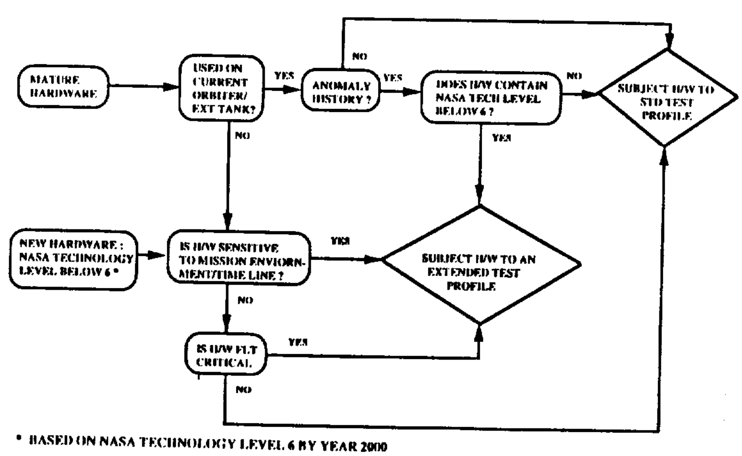


Figure 4-8. Qualification Test Logic.

requirements and the selected test or analysis approach will be addressed in the certification plan and defined in the individual test plans.

Ground/Flight Verification Tradeoff. Flying without prior ground testing would impose unacceptable risks, and qualification of all hardware totally by ground test would minimize flight risk but would result in much higher cost. The key objectives, then, are to determine how much testing must be done on the ground to optimize the risk-cost trade and what level of assembly, what environmental levels, and what durations should be used to attain a reasonable flight -worthiness level. Consistent with these objectives, ground test at the appropriate level, duration and/or safety factor will be required to demonstrate a specific number of missions or total design life when hardware is flight critical or has an adverse history.

All noncritical and relatively non-sensitive hardware will be subjected to flight worthiness testing for selectively determined duration. Flight worthiness testing will be conducted for a period determined to exceed the "infant mortality" period to detect failures likely to occur early in qualification testing. This will be based on space and aircraft program experience. Additional life test data will be accumulated on noncritical hardware during the flight test program. Flight worthiness concept for cost avoidance is justified on noncritical hardware based on AMLS failure-tolerant design, including fail safe (minimum design), fail operational/fail safe for functionally critical items and self test capability.

Performance data on both critical and noncritical hardware gathered during the testing phases will be disseminated and modeled to establish limits on vital parameter data which will be monitored to determine the health of the hardware.

The airlines have correlated ground test duration to the number of flight hours planned prior to scheduled major inspection. The airline approach to certification prior to allowing passenger flights will provide guidelines relative to the number of AMLS missions that should be simulated on the ground on noncritical hardware prior to flight.

Except for very thermal sensitive items that may require over temperature stressing, it is anticipated that segments of the orbiter and booster will be subjected to thermal-vacuum testing. Critical subsystems sensitive to thermal/vacuum environments will be life tested using accelerated thermal test techniques.

It is also anticipated that segments of the orbiter and booster will be subjected to vibro-acoustic environments. The vibro-acoustic environment has not been modeled for the AMLS. If the predicted environment is sufficiently mild it may be risk tolerant and cost effective to subject only critical items with vibration sensitive components to a vibro-acoustic environment. The qualification logic for vibro-acoustics and thermal-vacuum are shown in Figure 4-9.

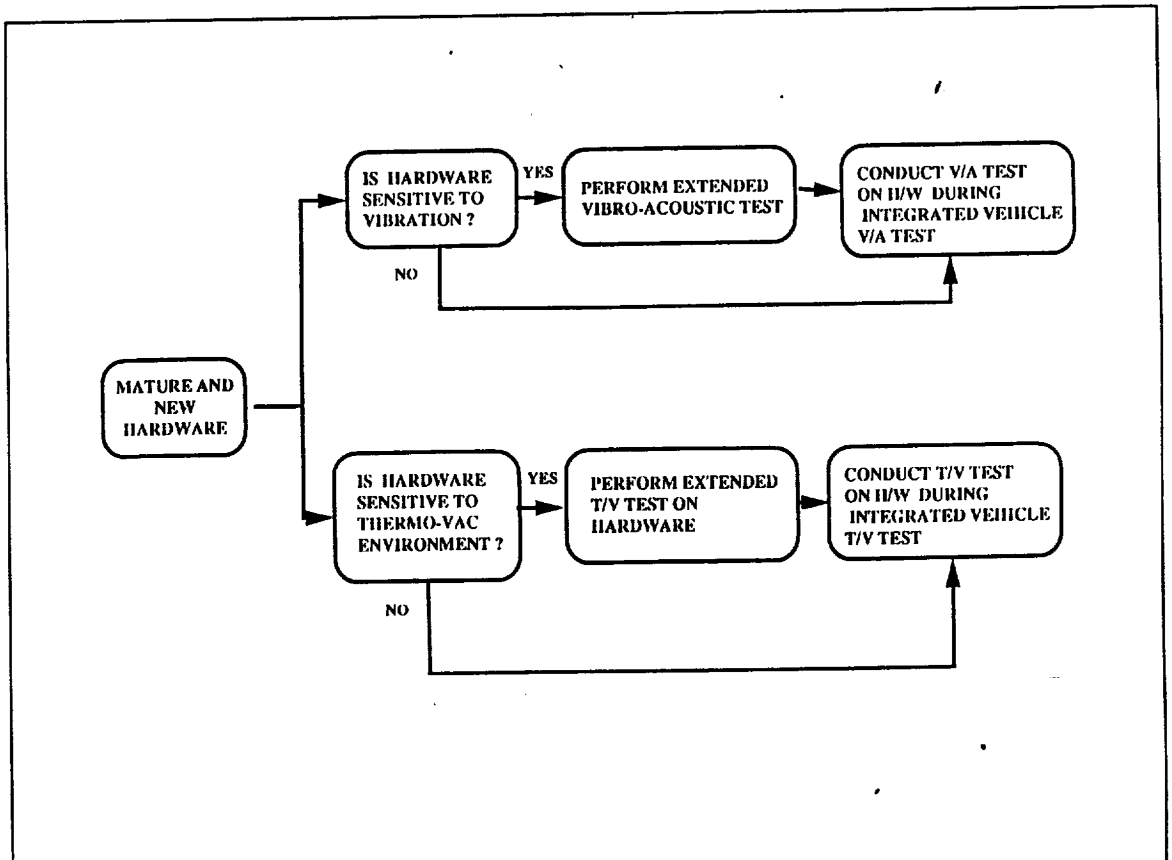


Figure 4-9. Vibro-Acoustics/Thermal-Vacuum Qualification Logic

Off-Limit, Overstress and Abort Testing. Off-limit and over stress testing will be performed to identify design margins on flight critical hardware, when design margins are relatively small, on long lead items or items difficult to replace and when uncertainty exists in environmental data for abort conditions and single failure points. A Shuttle orbiter study indicated that approximately 25% of the vehicles hardware parts were candidates for overstress testing. Use of current state-of-the-art components and mature hardware should substantially reduce the percentage of candidates on AMLS.

Off-limit and over stress testing will subject hardware to conditions that exceed the design and qualification requirements. Test objectives will be used to determine how much excess stress/environment critical units can withstand prior to reduced performance or malfunctioning to provide confidence that identified failure modes related to potential flight safety failures will be minimized if not eliminated. Orbiter studies have shown that off-nominal abort conditions could generate the most probable over stress conditions. These tests will provide confidence towards achieving low life cycle costs.

Subsystem Testing. Test requirements for the AMLS will be derived from lessons learned from the orbiter, predicted environments and applicable military and NASA specifications. The logic planned to achieve structural verification is illustrated in Figure 4-10.

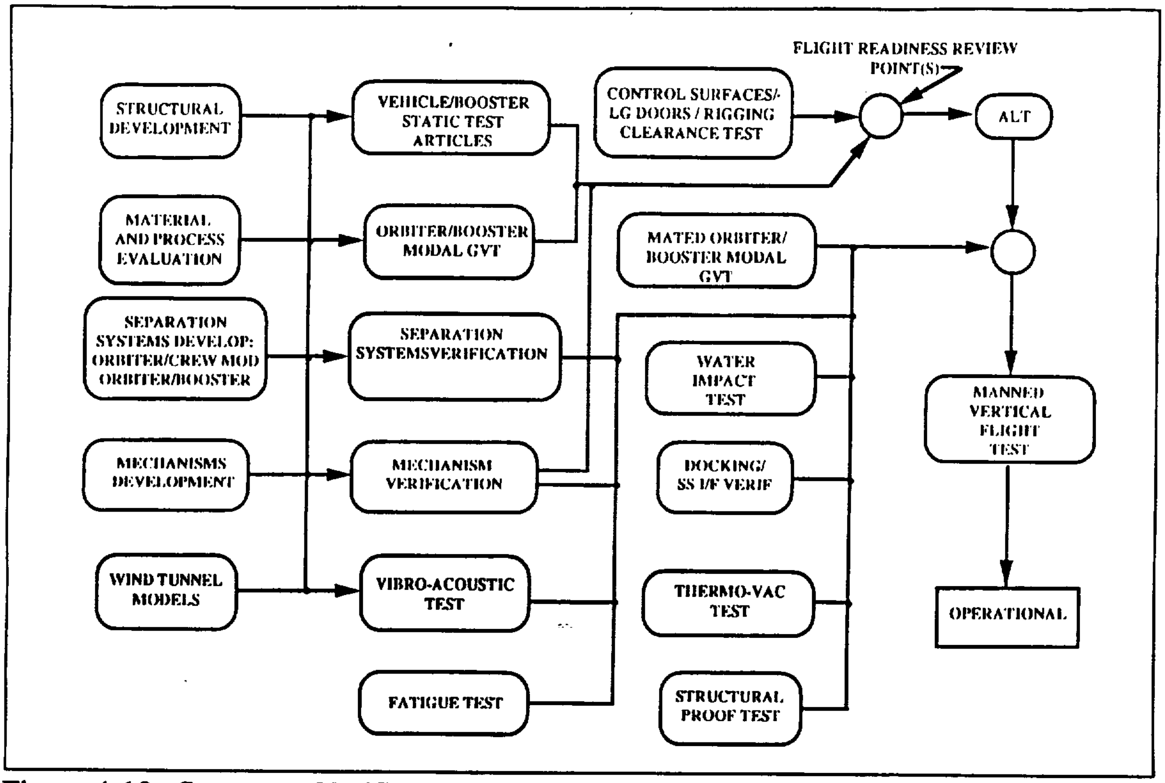


Figure 4-10. Structures Verification Logic.

The structural ground test program will begin with material evaluation. Material testing will fall into four categories: material control, fracture control, material characteristics development, and processing development. Though the AMLS program intends to use mature, proven products , there may be some areas where new light weight state-of-the-art non-metallic materials will require life cycle testing for untried applications. Structural development tests will be performed to develop design optimization and develop confidence in the approach. Verification of the structure subsystem for critical design limit and ultimate loads will utilize full-scale structural articles. These tests, subsequent to structural development testing, will be carried to the point of destruction to develop performance data on overstressed conditions. The structural tests will be performed as the program matures and the purpose of these tests are noted on the figure. Modal frequencies, shapes and damping characteristics will be measured through ground shake testing to validate the dynamic math models.

Landing/Deceleration. The landing gear systems consist of a conventional tricycle landing gear with nose wheel steering and electric actuated brakes and anti-skid system. The intent is to use the landing gear system of a proven military or commercial aircraft modified to meet system requirements. This approach should bypass the landing gear problems experienced by the orbiter. After the landing/deceleration system has been verified in the lab, a suitable aircraft will be equipped with the AMLS gear to further verify performance and capability before the Approach and Landing Test (ALT).

Docking. The orbiter's upper, forward portion of the housing for the payload containment system, PCS, will contain the structure and mechanisms to acquire and interface with the proposed space station docking system. The docking test program will verify structural integrity, mechanism performance, ability to dock and lock under various conditions of alignment, and demonstrate the emergency separation system.

Thermal Protection and Control. Wind tunnel tests and math modeling of the orbiter for ascent, on orbit and decent profiles will provide the design-to requirements for thermal protection (TPS) and control (TCS). Initial development and testing of the TPS, which is expected to be part new materials and part refinement of the orbiter TPS, will be performed at the supplier. Principal TPS tests will verify thermal properties and performance characteristics, structural integrity, ability to adhere to the substructure, wear and handling properties and repair capabilities. Thermal control tests will verify heating and cooling performance.

Orbit Maneuvering (OMS) and Reaction Control (RCS) Systems. The OMS and RCS are functionally independent but have the common purpose of powering the vehicle in orbit. Both use pressure-fed LO_2/LH_2 propellants contained in tanks and distributed to the propelling thrusters through lines and valves. The intent is to use proven components/systems adapted/modified to AMLS requirements which would minimize development testing. The OMS and RCS static firing test programs will be conducted to verify subsystem performance, response and the integration with related segments of the avionics and structural subsystems. Related ground support equipment (GSE) will be also be verified during this this test program.

Abort Separation Motors. The development and testing of the abort separation motors will be the responsibility of the suppliers using AMLS program generated requirements. Integration tests will be conducted to verify trajectory performance, ballistic reproducibility, interface release system and structural integrity. The separation motors will be tested with a crew compartment boilerplate to assure that the crew compartment will separate properly from the orbiter for abort activities.

Avionics. The avionics consist of hardware and software that provides sensing, computation, display controls and communication functions. Avionic testing as well as other test programs will be influenced by the test philosophy of the airline industry. Current studies are in work to review airline testing methods and the philosophy behind these methods and procedures to be able to apply cost and time saving measures which, hopefully, will add little or no risk to the verification program.

The process for verifying AMLS avionics is depicted in Figure 4-11, which begins with requirements and concludes with flight testing. Principal avionics test requirements to be imposed on the AMLS program are listed below:

- Establish interface compatibility among newly designed, modified, and mature equipment and performance
- Verify adequacy of EMC measures

- Verify adequacy of fault detection, tolerance and recovery during time-critical hard-over flight control failures
- Establish avionics compatibility with non-avionic interfaces
- Verify booster unmanned flight capability
- Verify man-machine interface
- Verify software and the ability of interfacing computation systems to meet requirements
- Verify communication systems
- Verify navigation systems
- Verify adequacy of power and its distribution system
- Verify self-test capabilities
- Verify hardware replacement capabilities
- Validate ground checkout processes

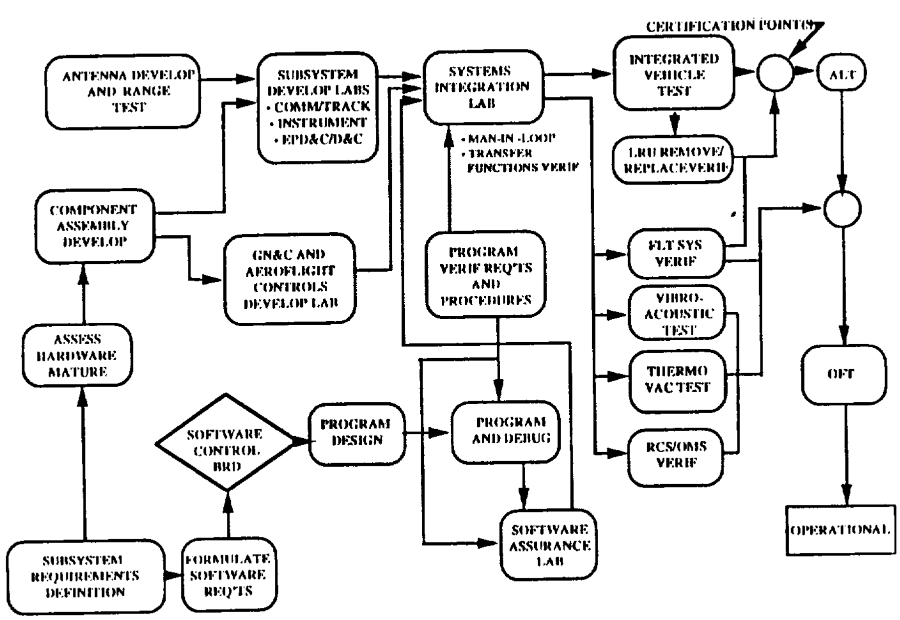


Figure 4-11. Avionics/Electronics Test Logic

<u>Environmental Control and Life Support (ECLSS)</u>. The ECLSS provides atmospheric revitalization, thermal control and life support functions. The atmospheric revitalization subsystem controls the crew cabin environment and manages the avionics and mechanical equipment heating and cooling requirements. Life support provides for food and waste management and fire control. It is anticipated that most if not all of the ECLSS components will be developed and individually verified by suppliers. The principal tests to be performed include:

Atmospheric Revitalization:
- Demonstrate air cabin temperature control
- Verify performance of O2 control
- Verify air distribution, temperature and humidity control with in cabin and avionics compartments
- Evaluate all materials used in cabin for toxicity and fire resistance

Life Support:
- Verify function of food and waste management subsystem in a zero-g environment
- Verify performance of the atmospheric contaminant and fire detection system

Parachute and Water Impact Tests. Unmanned boilerplates of the crew compartment will be subjected to ground and water impact tests. The boilerplates will have form, fit and CG and will contain mockups of equipment not uniquely required to support the tests. After the parachute design is adequately verified through analysis and single chute drops, boilerplate vehicles equipped with flight configured parachute system will be jettisoned from the cargo bay of a large aircraft, possibly a C-5A or a C-17.

4.3.5 Flight Test Program.

The AMLS flight test program will be designed to validate the models used to predict environments and flight parameters, mission compliance, and demonstrate separation, landing/deceleration and turnaround capabilities. It will be organized into segments adressing Approach and Landing Tests and Orbital Flight Tests.

Approach and Landing Test (ALT). The ALT is a suborbital flight test program designed to achieve the objectives listed on Table 4-3. There will be three ALT flights each for the orbiter and booster. Both the orbiter and the booster will be modified to provide for attachment points to permit latching the vehicles to suitable aircraft. Current design may require the orbiter to be piloted by a single crew member. This constraint is governed by cabin size which has room for only one ejection seat and still provide adequate ingress and egress. The single pilot, which reduces human risk, will be supported and backed up by autoland capabilities. The ALT orbiter will be further modified by not incorporating the propulsion systems, docking system, portions of the ECLSS and power systems and passenger seats and provisions. It is not anticipated that the ALT orbiter will be serviceable as an orbital craft. Similar deletions and modifications will be made to the booster.

Table 4-3. Approach and Landing Test.

THE ALT PROGRAM IS INTENDED TO DEMONSTRATE THAT THE ORBITER AND BOOSTER CAN PERFORM AS INTENDED IN THE ATMOSPHERE BY ACHIEVING THE OBJECTIVES LISTED BELOW:
OBJECTIVES:
o AUTOLAND PERFORMANCE
o LANDING GEAR, TIRE & BRAKE PERFORMANCE
o LOW SPEED AERODYNAMIC CONTROL AUTHORITY
o CG. ENVELOPE SENSITIVITY
o CROSS WIND LANDING SENSITIVITY
o VEHICLE PERFORMANCE UNDER WEIGHTED CONDITIONS
o FINAL APPROACH ENERGY MANAGEMENT

Table 4-4. Orbital Flight Test Objectives.

THE ORBITAL FLIGHT TEST PROGRAM IS DESIGNED TO VALIDATE MODELS AND ANALYSES USED TO PREDICT ENVIRONMENTS AND FLIGHT CONTROL PARAMETERS AND TO DEMONSTRATE SEPARATION, LANDING, AND TURNAROUND PERFORMANCE.
THE (MATH) MODELS AND ANALYSES TO BE VERIFIED INCLUDE:
o AERODYNAMICS
o THERMAL - TPS/TCS
o VIBROACOUSTICS
o EXTERNAL LOADS
o VENTING
o AEROTHERMAL
o CONTROL LOOP PARAMETERS

Orbital Flight Test (OFT). The orbital flight test program will satisfy the objectives listed in Table 4-4, and demonstrate the orbiter's flight worthiness and mission capability extending the flight envelope to include mated ascent, separation, orbit insertion, on-orbit operations, and entry. The OFT program comprises four orbital flights, with two possible contingency flights (one or more of these may be unmnanned). The contingency flights are planned in the event anomalies or natural causes prevent satisfying stipulated requirements within the allotted flights.

During both the ALT and OFT programs, operational instrumentation, OI, will be supplemented with development flight instrumentation, DFI. The DFI will be oriented towards acquiring data not normally addressed by OI but in some cases as extension of OI. Both the OI and DFI data will be used to validate models and provide information regarding the performance of the AMLS. A master measurement list for all OI and DFI will be generated prior to the flight test programs and maintained throughout the life of the AMLS program.

At least one of the orbital test vehicles will be load calibrated to establish a yardstick for the installed strain gauges to assure accurate stress analysis. The DFI will be removed or at least substantially reduced at the completion of the orbital flight test program.

4.3.6 Facilities.

Based on the work break down structure, the MFBP's, the recommended test plans, available make/buy information, the program and manufacturing schedules, potential major sites and facilities for manufacturing and test were identified. Basic initial facilities area requirements for: Rockwell International, Space Systems Division: Downey and Palmdale, CA, and Kennedy Space Center (KSC), FL; North American Aircraft: Tulsa, OK, Palmdale and El Segundo, CA; Johnson Space Center (JSC), Houston, TX; Edwards Air Force Base (AFB), CA; Langley Research Center, Va. and White Sands, NM were determined.

4.3.7 Summary

The highlights of the integrated test program configured for the AMLS have been delineated in the body of this report. During the early portion of the test program, emphasis will be placed on building a firm foundation through aggressive development testing to achieve low cycle costs during the operational phase. This approach will be further enhanced through selection of proven products with reliable up to date state-of-the-art properties. Stress testing will be implemented in phase A and continue throughout the ground test program to detect design flaws that could perturbate operational costs and detrimentally effect turnaround times.

Since it is anticipated that a major portion of the AMLS development and product program will be farmed out to subcontractors, the subcontractors will be required to operate under comprehensive test requirements and guidelines with SSD personnel in constant contact and periodic attendance.

Military and commercial airline test program procedures and policies will be reviewed and studied in SSD's approach to definitively develop the most cost effective, risk acceptable integrated test program for the AMLS that will achieve reliability at low life cycle costs. Furthermore, costs will be controlled through avoidance of proliferation of test articles and requirements for new facilities by:

- Providing a systematic method for identifying, screening and allocating test requirements using analysis and simulation to supplement testing and satisfying multiple subsystem test requirements on major test articles.

- Minimizing single purpose high cost test hardware.

- Avoiding new construction by utilizing existing facilities to the maximum extent.

- Accomplishing the final interface checkout of the launch facilities by using the first flight article rather than a special "test only" vehicle.

- To assure that no loss of design maturity or hardware integrity is incurred as a result of minimizing tests and test articles, SSD plans to:

- Qualify all hardware through maximizing the use of analysis and similarity to supplement testing and using data from previously run programs, where feasible, to minimize qualification testing.

- Incremental certification to assure that each subsystem and system is ready for the next milestone.

Ground support equipment , GSE, is an integral part of the AMLS integrated test program and full attention will be paid to its need and development to assure cost effective applications.

4.4 SAFETY AND RELIABILITY

The aspects of safety and reliability were addressed during the study, but no formal safety plan or hazard analysis was performed. The reliability requirements for design, logistics and operations are defined in Reference 4-5.

4.4.1 Safety.

The AMLS design requirements have been developed with full understanding that the number of potential hazards are influenced by the design itself. The preferred AMLS concept has many design requirements characteristics that will reduce the number of hazards requiring control. For example:

- Electro-mechanical Actuators (EMA's) - Hydraulics and auxiliary power units (APU's) are not necessary to support he aerosurfaces, landing gear and brakes.
- Advanced TPS design - Reduction of mission to mission maintenance.
- Landing Gear - Design to accommodate maximum weight and landing crosswinds.
- Avionics -Failure tolerant design to allow mission continuation after failure.

A detailed hazards analysis for the AMLS will be performed during a later development phase. The intent of any design and specifically the AMLS is to reduce or control the number of hazards the final design presents to the operational phase of the program. Two hazard levels which can not be eliminated, but all initial and final design effort should try to control them. They are; (1) Catastrophic hazard, like the loss of the booster due to time critical failure, and (2) Critical hazards requiring an emergency action by the crew or system. These must be addressed, understood, and controlled or risk understood and approved by the program office.

4.4.2 Reliability.

In addition to reliability data presented in Reference 4-5 the approach to redundancy of critical paths should be examined. Redundancy increases system reliability, but at the cost of increased complexity in fault detection, isolation and control. A study needs to be performed to establish a system to balance the gains in reliability vs. the impact on operations and mission success resulting from false alarms.

System reliability can be increased with good system design and not increase maintenance requirements, by the selection a good overall system architecture and reliable parts selection and placement in critical areas/functions.

The probability of crew survival and mission success should determine redundancy levels. It can easily be shown that a system that has 3 or 4 strings or a fail operational/fail operational/fail safe (FO/FO/FS) using poor quality parts and a poor system design could have a probability of mission success less than a FS system with quality parts and a clever system design.

Even when parts and architecture are optimized, redundant systems often add complexity to other systems. For example, one must incorporate more sensors, and MDM like interfaces, etc., to be able to detect a fault in a system. These extra components reduce the reliability in other systems by adding parts and complexity. In addition, the adding of the fault isolation and control functions also includes the possibilities of errors in fault detection. In other words, false alarms resulting from detection complexity could reduce overall mission success probabilities as well.

A compromise must be reached between reliability, maintainability and redundancy levels. One of the most difficult engineering decisions is what success probability is acceptable.

4.5 QUALITY ASSURANCE

This subject will undergo perhaps the single most significant series of changes during the AMLS program life cycle. The quality program specifications developed during the 1960's and 1970's will undergo a fundamental refocus of requirements, which incorporates the precepts of the TQM (Reference 4-3) initiative of the 1990's info the objectives of the quality specifications. This is not to imply that these will or should be discarded, for one significant factor to success in manned spaceflight has been that of strict and disciplined attention to details - a well-known characteristic of quality programs.

The quality programs of the 1970's/1980's were also generally not addressed with any significance until the Phase C/D arrived, the premise being that emphasis on compliance, controls, procedures, and verification did not occur until then. The AMLS quality program will have its formal beginning during Phase A. It will be a dedicated emphasis. It is particularly important because of the transitional nature of TQM expansion across industry/government during the same time frame as the AMLS program. Elements of this TQM emphasis are already beginning to be reflected in this DRD. Operations/Maintenance emphasis is, we believe, a strong "Customer Want" for improving turnaround efficiency and lowering the life cycle cost. The MFBP concept is the very beginning of development of detailed process flows and process capability assessments, providing efficient blending with the Government's IQue oversight initiative.

4.5.1 Phases A and B.

During Phase A, it is extremely important that the top-level quality functional deployment (QFD) matrices be addressed. The basic premise of "Total Quality" starts with true understanding of "what the Customer really wants" and approaches to help provide it to him. Since approaches can impact basic architectures (e.g. the maintainability approach), they need to be addressed as early as possible to avoid costly engineering changes later in the program. This is a characteristic of our Japanese competitors. They "drive out" changes before commitment to manufacture.

Two of the highest correlation "wants" (QFD terminology) to implement, for example, have been those of: (1) systems simplicity and (2) that of defining the operational fault tolerance needed and the redundancy management schemes to support it. This correlation is increased when moderate-to-extreme weight/volume and resultant performance sensitivity exists from the very beginning. One example, is performance margins which can tolerate a major failure condition right after launch commitment. The impact of this example to the Phase C/D quality program to be implemented is profound! Understanding of processes, their variability and reduction of their variability are main themes. As fault tolerance declines, permissible variation rapidly declines. A program intolerant to variation can emerge. Conversely, with a fault tolerant design approach, variability reduction can be safely implemented (as well as better understanding obtained over those areas still remaining which remain intolerant).

Phase B should then form the next set of quality program foundations. This phase must see convergence of a number of efforts, (for example: QFD/sub-tier matrices, development convergence with MFBP, design system organization with MFBP (part, sub-assembly, assembly number "trees", critical process definition and flow down into process requirements/capabilities trades (starting here also to bring the knowledge of critical subcontractors onto the team). The initial formation of formal simúltaneous engineering teams takes place. The quality program for Phase C/D needs to be specifically and fully planned here specifically including the particular MIL-specification/TQM transition timing as discussed earlier. Advanced technology integration, in the process of historical hard interface control tooling vs. electronic interface control, and related process control parameters, needs to be specifically defined.

As the MFBP continues development, definition of process parameters also will continue. This includes an objective of measurements made of products conformance in as real-time as possible (such as, weld ultrasonic head mounted right behind weld head). Use of statistical process control (SPC) (Reference 4-6) also needs to be structurally organized during this phase, so that SPC is not just a "randomly-applied" tool.

4.5.2 Phases C and D.

The quality program needs to focus on as many of the "fundamentals", now integrated into TQM initiatives. The focus is initially on prevention of defects, development of process flows and capabilities determinations, application/definition of "work teams" (cross-function), training of teams, readiness to perform tasks and increased individual involvement in doing the right things right, the first time. These "work teams" are expansions of the "design teams" from the prior phases.

The quality program must here maintain fundamental assurances of stability and control to the Customer. Therefore, calibration validity of measurements, engineering change control (which should be minimized with the up-front Phases A and B emphasis), nonconforming parts/materials control, test and records integrity, etc. must be addressed and any issues resolved by the assigned "work teams". The objective of achieving program success, by providing outstanding value to the Customer with outstanding first-time thru quality at reasonable cost and a dependable schedule, is fully definitized and implemented during this phase.

The quality program requirements specification [MIL-Q-9858 A] tailoring activity was deferred during the Pre-Phase A Study Contract, as identified in DRD-2 (Reference 4-7), until hardware procurement in Phase B and/or C/D. Tailoring of the specification will be an on-going process as part of refining the acquisition plan.

5.0 OPERATIONS AND SUPPORT ANALYSIS

This section documents the Operations and Support Analysis portion of the study concentrating on the scenarios developed for ground, flight, and mission using an airline type approach to minimize manhour requirements and to provide effective and efficient operations. Selections and definitions for ground processing manhours, ground processing support staff, flight and mission staffing for support and training, mission/flight requirements, mission timeline, facility requirements, software analysis, Ground Support Equipment (GSE), and logistical support analysis procedures are documented in this report.

5.1 OBJECTIVES

The primary objectives for this phase of the study were to perform operations and support analyses for the AMLS vehicle mission to the Space Station Freedom (SSF). The operations and support activities included: 1) an assessment of the Reliability and Maintainability (R/M) features, 2) the definition of the ground operations requirements and the facilities and processing requirements, 3) the definition of flight and mission operations requirements for the AMLS, and 4) the definition and quantification of the support system and spares required to meet the AMLS flight rate.

5.1.1 Operations and Support Ground Rules

Many ground rules and assumptions were followed during the study to determine the most operationally efficient and effective ground, flight, and mission operational scenarios. These ground rules are documented in Section 2 of this report. The following is a summation of groundrules which apply directly to all phases of AMLS operations:

- NASA technology level 6 or better at expected Initial Operations Capability (IOC) date
- Orbiter and booster designed for vertical lift off
- Autonomous operations from pre-launch through landing within the limits of program constraints
- On-pad evacuation of AMLS within 3 minutes
- Continuous escape/abort capability
- Single main engine failure permitted on each flight element
- Common propellant for all AMLS propulsion systems
- EVA provisions for two trained crewmen
- Kennedy Space Center (KSC) is the primary launch and landing site

The following summarized groundrules are directly applicable to ground operations and were used during the development of operational scenarios and concepts:

Orbiter and Booster

- Aircraft-like techniques and methodologies where appropriate with a progressive program of scheduled hardware and software maintenance activities
- Ease of access for maintenance and inspections
- Minimized/eliminated: 1) number/types highly toxic or corrosive fluids, 2) use of pytotechnics
- Adequate spares to avoid cannibalizing
- Cleanliness levels within the AMLS crew module to comply with Space Station Environmental Requirements
- Elements capable of ferry by land, sea, and air using existing commercial or government transport systems with minimum specialized GSE
- All unique AMLS facilities at the launch site are new

Payload Containment System (PCS)

- Modularized PCS with customized PCS's for alternate Design Reference Missions (DRM)
- High degree of payload manifesting capability with numerous discrete attachment points
- AMLS orbiter provides safety status monitoring of payload functions (direct and relay telemetry and command with attached and released payloads)
- Standardized power and environment levels supplied through standardized interfaces (Power/environment in excess of standard values provided by and charged to the payload)
- Late payload access for minimal service at the launch pad (not nominal, but payload option)

The following summarized groundrules directly applicable to mission operations were used to develop flight and mission operational scenarios and concepts:

- Two crew and eight passengers to and from the SSF at 220 NMI (250 NMI maximum) at 28.5 degree inclination
- 72 hour mission duration plus 12 hours for contingency (35 man-days)
- Deliver/return 15 ft diameter by 30 ft length payload, maximum weight of 40,000 lbs.
- Booster unmanned with glide back to launch site runway
- Autonomous variable launch azimuth capability
- AMLS orbiter active vehicle when docking with the SSF
- Autonomous vehicle operations while docked to the SSF
- Mission sequences automated with crew take-over capability

5.1.2 Assumptions

Along with the ground rules provided above, the following assumptions were followed to provide operational benefits including design drivers for: 1) accessibility, 2) maintainability, 3) maintenance, 4) health monitoring requirements, and 5) use of BIT/BITE circuitry.

- Standardized flight operations (loads and missions) to reduce support resources needed to reconfigure and plan each flight.
- On-board health monitoring during missions to provide the historical database used for determining maintenance activities. Only those systems requiring repair will be recertified, following aircraft type operational scenarios.
- Generic Airframe and Powerplant (A & P) personnel to reduce the number of skill mixes required, thus minimizing processing time and technician requirements.
- Low cost aircraft type (open bay) orbiter and booster processing, mating, and storage facilities,built using standard construction techniques and materials, providing flexibility at a low cost.
- Multiple mating and processing bays to ensure integration capability.
- Open bay facility sizing to permit contingency operations, such as the replacement of a large structure or the positioning of GSE required in an emergency situation.
- Payload Containment System Processing Facility (PCSPF) to use standardized procedures and operations to accommodate three types of PCS operations:
  - PCS arriving fully integrated,
  - Single large payload requiring PCS integration, and
  - Multiple payloads requiring integration.
- Minimal payload checkout and verification operations performed.
- Pad stay time minimized.
- Access to payloads at the pad limited to access to the outer PCS shell where operations such as battery change out may be performed. Payload operations will not be considered a "normal" operation.
- Single Launch/Mission Control Center (L/MCC) located at the launch site to permit consolidation of launch commit criteria and permit efficient and effective use of resources and personnel. Common operational data base utilized to support all operational phases.
- Initial fleet sizing assumptions of five orbiters, five boosters, and ten PCS's (See Section 5.3.2. for fleet sizing analysis).

5.1.3 Study Tasks

The study concentrated on determining the ground, flight, and mission requirements associated with the AMLS mission to the SSF. A database was developed to support this activity and includes the following study tasks results:

- R/M Tables to identify maintenance and operations impacts for the AMLS configuration. Data was developed using the MAtrix model and is in the same format provided previously for Study Tasks 1 and 2.
- Facility requirements for ground and flight processing activities and organizations.
- Timelines reflecting orbiter, booster, and PCS processing, integration, launch, and mission operations.
- Manpower tables reflecting the allocation of personnel.
- Software analyses for ground and flight mission phases.
- Recommended spares tables for the orbiter and booster elements reflecting AMLS requirements.

Functional flow block diagrams were developed to help develop the ground and flight operational scenarios. In addition, various top level trades were performed to determine the most efficient and effective operational scenarios and facility configurations.

5.2 RELIABILITY AND MAINTAINABILITY

Comprehensive R/M analyses and assessments have been conducted on the orbiter and booster vehicles and their major systems and components. These quantitative R/M analyses provided the "yardstick" to measure the degree of R/M and Supportability inherent in the candidate design configurations. Objectives of the R/M analysis and assessment activity were to:

- Identify unacceptable R/M characteristics of the evolving AMLS designs such that undesirable features can be eliminated prior to the initiation of detailed design. Similarly, R/M analyses identify the need for design and support features that should be incorporated. Results indicate, for example, that booster avionics, from a mission reliability perspective, may not need redundancy provisions but that triply redundant avionics appear to be warranted for the orbiter.
- Provide numerical R/M parameter values for use by the Operations, Logistics and Life-Cycle Cost disciplines.
- Provide R/M data for use in trade studies.

The R/M analysis and assessment activity was accomplished utilizing a model entitled "MAtrix," a parametric R/M estimating tool developed by Rockwell specifically for use in conceptual and preliminary design phases. MAtrix estimates values for key R/M parameters (at the vehicle, system and component levels). Recently developed subroutines provide for the estimation of Mission Completion Success Probability (MCSP). Numerical values for the following parameters were estimated for the orbiter and booster, and their major systems and components.

- MTBM (mean-time-between-unscheduled maintenance).
- MTBF (mean-time-between-failure).

- MTBR (mean-time-between-removal).
- MTBCF (mean-time-before-critical-failure).
- MTTR (mean-time-to-repair).
- Unscheduled Manhours per Mission
- Scheduled Manhours per Mission.
- MCSP (Mission Completion Success Probability)

5.2.1 Preliminary R/M Assessment

A preliminary parametric analysis with MAtrix yielded a set of design-related R/M parameter values at the system and component levels. Inputs to MAtrix were exclusively derived from LaRC-furnished system definitions and estimated weights. The document entitled "AMLS Two-Stage LaRC Baseline Vehicle Description" was used for additional information and guidance. Current technology levels (i.e., technologies available off-the-shelf in FY 1991 - Avionics systems utilized 1985 technology level [0.004942] and all other mechanical and structural equipment utilized 1965 technology level [0.013319]) were assumed for this and subsequent R/M analyses. This assumption provided conservatism in all R/M analysis results. Preliminary assessment results, formally provided to NASA during the June 4 - 5, 1991 Interim Review at LaRC, are displayed in Table 5-1.

Table 5-1. Preliminary AMLS R/M Assessment Results.

MATRIX INPUTS/OUTPUTS	ORBITER	BOOSTER	COMBINED
Flight Duration (Hours)	72.000	0.239	-
Main Engine Burn Time (Hours)	0.136	0.333	-
Unscheduled Maintenance Actions/Mission	112.150	18.970	131.120
Removals/Mission	31.580	5.010	36.590
Failures/Mission	48.1000	6.830	54.930
Unscheduled Manhours/Mission	504.670	85.360	590.030
Scheduled Manhours/Mission	277.570	49.950	327.520
Mission Completion Success Probability	0.9855	0.9970	0.9825

* Note: Preliminary R/M assessment based on weights from initial LaRC analysis

5.2.2 Updated R/M Assessment

Subsequent to the June 4 - 5, 1991 Interim Review at LaRC, additional design data became available as a result of Rockwell's in-house AMLS activities. In particular, this data provided estimates of the quantities of Line Replaceable Units (LRUs) expected to comprise the various orbiter and booster systems. LRU quantity data heretofore had not been available. This new data also contained revisions to estimated system weights. As a result, a more thorough R/M analysis was conducted and, as a result, preliminary results were considerably enhanced and updated. Results of this second iteration are summarized in Table 5-2. The MCSP range of 0.9688 to 0.9907 is a function of

Avionics System redundancy options. The orbiter baseline value of 0.9688 (no redundancy) increases as the redundancy is increased (0.9868 if 1 of 2 avionics LRUs is required for mission success and 0.9907 if 1 of 3 avionics LRUs is required for mission success). The resulting range represent the options available, subject to trade studies involving weight, cost, etc.

Tables 5-1 and 5-2 both indicate that significant differences exist between the orbiter's and the booster's estimated expenditures for maintenance. At first, the difference may not seem reasonable considering the similarities in sizes and complexities of the two vehicles. The orbiter's dry mass is about 1.5 times the dry mass of the booster, and each vehicle has the same number of SSME-derivative Main Engines. All other things being equal, one might reasonably expect the orbiter to require 1.5 to 2 times as much maintenance per mission as the booster. However, analysis reveals that the orbiter will require about 8 times as much maintenance per mission as the booster.

The significant difference is almost solely attributable to variations in mission duration and Main Engine burn times. The orbiter's nominal mission duration is 72 hours, while the booster's is less than 0.25 hours. Moreover, the orbiter's Main Engine burn time of 0.136 hours is approximately 4 times longer than the booster's Main Engine burn time of 0.033 hours. When the orbiter's mission time is reduced to match the booster's mission time the differences in their maintenance requirements become more intuitively satisfying. Figure 5-1 illustrates how orbiter unscheduled maintenance actions per mission approach booster unscheduled maintenance actions per mission as orbiter mission time is reduced to approach that of the booster. With a mission time of 0.239 hours each, the orbiter's unscheduled maintenance actions are 1.5 times the booster's unscheduled maintenance actions, a result consistent with the relative sizes and complexities of the two vehicles.

Table 5-2. Updated AMLS R/M Assessment Results.

MATRIX INPUTS/OUTPUTS	ORBITER	BOOSTER	COMBINED
Flight Duration (Hours)	72.000	0.239	-
Main Engine Burn Time (Hours)	0.136	0.033	-
Unscheduled Maintenance Actions/Mission	123.920	15.930	139.850
Removals/Mission	24.800	4.190	28.990
Failures/Mission	44.170	5.980	50.150
Unscheduled Manhours/Mission	557.660	71.700	629.360
Scheduled Manhours/Mission	306.710	39.440	346.150
Mission Completion Success Probability	0.9688 -0.9907	0.9973	0.9662 -0.9880

The R/M Analysis process yielded the steady-state R/M values that can confidently be expected when the AMLS is put into operations. The analysis was suitably factored to account for reliability growth based on observed Shuttle Orbiter experience. Table 5-3 presents a representative section of our detailed R/M analysis with MAtrix.

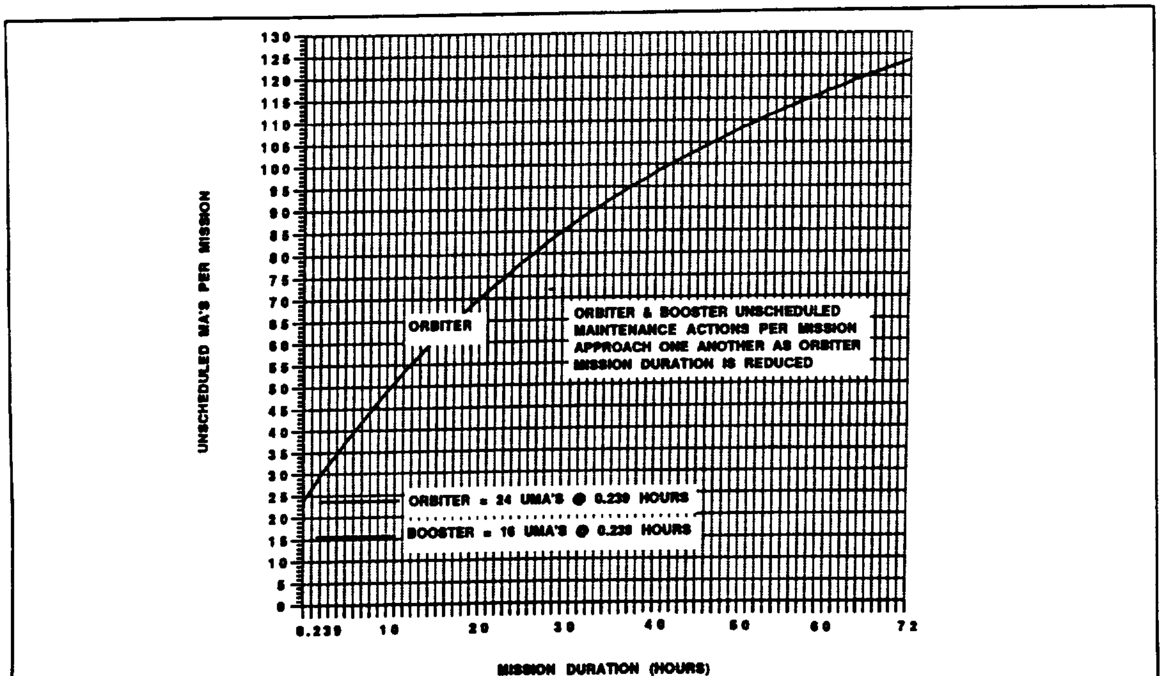


Figure 5-1. A Graphical Display of How Orbiter and Booster Maintenance Expenditures Relate to One Another.

Table 5-3. R/M Analysis (Representative Section).

ORBITER	QTY	UNIT WT (LBS)	TOTAL WT (LBS)	MTBM (FLT HRS)	MTBR (FLT HRS)	MTBF (FLT HRS)	MTBCF (FLT HRS)
Wing Group	-	-	27,1293..0	29	107	84	226,963
Wing Body	1	14,023.0	14,023.0	56	207	162	439,174
Gear Support, Fairing, Tip Fins	1	13,106.0	13,106.0	60	222	174	469,704
Tail Group	-	-	0.0				
Fin (Not Used)	1	0.0	0.0				
Body Group	-	-	61,831.0	14	52	40	119,933
Hydrogen Tank	-	-	22,611.0	35	127	100	272,331
Structure	1	19,379.0	19,379.0	40	148	116	317,763
Insulation	1	3,232.0	3,232.0	242	895	702	1,904,762

To achieve analytical credibility, as well as to provide traceability, it is often desirable to compare the R/M projections for a conceptual design (such as the AMLS orbiter) to the actual R/M experiences of a similar, but mature operational, design. With the exception of the Shuttle-Orbiter, no known vehicle exists for direct comparison with either the orbiter or the booster. The USAF C-5A cargo/transport aircraft provides some help in this regard since it is large, complex and contains systems functionally similar to AMLS orbiter and booster systems.

A summary of C-5A maintenance characteristics at the major system level is shown in Table 5-4. This data, reported by the USAF, encompasses a reasonably large experience sample (54,000 flying hours). Average flight duration was 1.39 hours. Note that the unscheduled maintenance actions per 1.39 hour mission (UMAs PER MISSION) were 9.984. These unscheduled maintenance actions required an expenditure of 46.537 unscheduled manhours (UMMH PER MISSION).

Table 5-4. USAF-Reported C-5A Maintenance Characteristics

WUC	C-5A AIRCRAFT USAF-REPORTED DATA FOR AN AVERAGE FLIGHT OF 1.39 HOURS	MTBM (HOURS)	UMAs PER FH	UMMH PER FH	UMHRs PER MA	UMAs PER MISSION	UMMH PER MISSION
11	AIRFRAME	0.8699	1.1496	5.0237	4.370	1.598	6.983
12	COCKPIT/FUSELAGE COMPARTMENTS	1.7889	0.5590	2.3590	4.220	0.777	3.279
13	LANDING GEAR	1.0579	0.9453	4.5964	4.862	1.314	6.389
14	FLIGHT CONTROLS	2.6178	0.3820	2.6669	6.982	0.531	3.707
23	TURBOFAN POWERPLANT SYSTEM	0.7796	1.2827	5.2410	4.086	1.783	7.285
24	AUXILIARY POWERPLANT	8.3752	0.1194	0.7108	5.950	0.166	0.988
41	AIR CONDITIONING/PRESSURIZATION	3.0960	0.3230	1.2129	3.755	0.449	1.686
42	ELECTRICAL POWER	5.2247	0.1914	0.7504	3.921	0.266	1.043
44	LIGHTING SYSTEM	4.1254	0.2424	0.6619	2.731	0.337	0.920
45	HYDRAULIC/PNEUMATIC POWER	3.0960	0.3230	1.2741	3.944	0.449	1.771
46	FUEL SYSTEM	4.8948	0.2043	1.4129	6.917	0.284	1.964
47	OXYGEN SYSTEM	19.5695	0.0511	0.1813	3.549	0.071	0.252
49	MISCELLANEOUS UTILITIES	4.4984	0.2223	0.9295	4.180	0.309	1.292
51	INSTRUMENTS	- 10.0000	0.1000	0.5417	5.420	0.139	0.753
52	AUTOPILOT	6.4641	0.1547	1.1137	7.200	0.215	1.548
55	MALFUNCTION DETECTION	1.9015	0.5259	2.4662	4.690	0.731	3.428
61	HF COMMUNICATIONS	24.3902	0.0410	0.2849	6.951	0.057	0.396
62	VHF COMMUNICATIONS	138.8889	0.0072	0.0460	6.429	0.010	0.064
63	UHF COMMUNICATIONS	77.5194	0.0129	0.0698	5.385	0.018	0.097
64	INTERPHONE	14.9477	0.0669	0.3396	5.075	0.093	0.472
65	IFF	72.9927	0.0137	0.0748	5.500	0.019	0.104
66	EMERGENCY COMMUNICATIONS	29.5858	0.0338	0.2676	7.912	0.047	0.372
71	RADIO NAVIGATION	21.7391	0.0460	0.2942	6.391	0.064	0.409
72	RADAR NAVIGATION	7.7640	0.1288	0.8273	6.426	0.179	1.150
91	EMERGENCY EQUIPMENT	18.7970	0.0532	0.1209	2.264	0.074	0.168
97	EXPLOSIVE DEVICES	344.8276	0.0029	0.0122	4.333	0.004	0.017
	TOTAL SYSTEMS =	0.1392	7.1825	33.4797	4.661	9.984	46.537

The booster estimate of 15.93 unscheduled maintenance actions per mission is close to what one might expect. A booster mission requires about as much maintenance as does two (2) typical flights of the C-5A. Since the USAF literally flies hundreds of C-5A flights per day, booster maintenance expenditures should be a negligible burden on NASA resources.

No aircraft routinely remains airborne for 72+ hours. However, it is possible to project what would happen, maintenance wise, if one did. Given that an adequate R/M history exists for known flight durations, and knowing what systems have cycle-based, time-based (or combined) failure dependencies, flights of any duration can be postulated and analyzed. Moreover, by substituting the less rigorous space environment for the terrestrial (aircraft) environment it is possible to hypothesize the maintenance outcome of long space missions flown by C-5As or any other aircraft.

Table 5-5 provides the results for a hypothetical 72 hour C-5A space-based mission. Note that 171.837 unscheduled maintenance actions are projected to occur per mission (UMAs PER MISSION), which will require the expenditure of 803.341 unscheduled manhours (UMMH PER MISSION). Observe, also, that Landing Gear requires the same number of unscheduled maintenance actions per mission (UMAs PER MISSION) as required for the Figure 5-4 (case 1.314). This result is due to the fact that Landing Gear has a cycle-based failure dependency. The C-5A's Landing Gear is used only during takeoff and landing, and is safely stowed during all other mission phases. Landing Gear maintenance is a function of missions flown, not hours flown.

Table 5-5. Projected C-5A Maintenance Characteristics for a 72 Hour Space Mission.

WUC	C-5A AIRCRAFT FOR A HYPOTHETICAL 72 HR MISSION IN THE SPACE ENVIRONMENT	MTBM (HOURS)	UMAs PER FH	UMMH PER FH	UMHRs PER MA	UMAs PER MISSION (SPACE)	UMMH PER MISSION (SPACE)
11	AIRFRAME	2.3804	0.4201	1.8358	4.370	30.246	132.175
12	COCKPIT/FUSELAGE COMPARTMENTS	4.8900	0.2045	0.8630	4.220	14.725	62.139
13	LANDING GEAR	54.9451	0.0182	0.0887	4.862	1.314	6.389
14	FLIGHT CONTROLS	7.1531	0.1398	0.9761	6.982	10.066	70.281
23	TURBOFAN POWERPLANT SYSTEM	2.1327	0.4689	1.9159	4.086	33.761	137.947
24	AUXILIARY POWERPLANT	22.8311	0.0438	0.2606	5.950	3.154	18.766
41	AIR CONDITIONING/PRESSURIZATION	8.4746	0.1180	0.4429	3.755	8.493	31.891
42	ELECTRICAL POWER	14.3472	0.0697	0.2733	3.921	5.019	19.679
44	LIGHTING SYSTEM	11.2613	0.0888	0.2424	2.731	6.391	17.454
45	HYDRAULIC/PNEUMATIC POWER	8.4746	0.1180	0.4652	3.944	8.493	33.496
46	FUEL SYSTEM	13.4048	0.0746	0.5161	6.917	5.372	37.158
47	OXYGEN SYSTEM	53.4759	0.0187	0.0663	3.549	1.345	4.773
49	MISCELLANEOUS UTILITIES	12.3153	0.0812	0.3393	4.180	5.844	24.428
51	INSTRUMENTS	27.2480	0.0367	0.1988	5.420	2.641	14.314
52	AUTOPILOT	17.6991	0.0565	0.4069	7.200	4.069	29.297
55	MALFUNCTION DETECTION	3.9541	0.2529	1.1860	4.690	18.207	85.391
61	HF COMMUNICATIONS	50.7614	0.0197	0.1370	6.951	1.419	9.863
62	VHF COMMUNICATIONS	294.1176	0.0034	0.0217	6.429	0.243	1.562
63	UHF COMMUNICATIONS	161.2903	0.0062	0.0337	5.385	0.450	2.423
64	INTERPHONE	31.0559	0.0322	0.1635	5.075	2.319	11.769
65	IFF	149.2537	0.0067	0.0370	5.500	0.485	2.667
66	EMERGENCY COMMUNICATIONS	61.3497	0.0163	0.1293	7.912	1.177	9.312
71	RADIO NAVIGATION	45.2489	0.0221	0.1414	6.391	1.593	10.181
72	RADAR NAVIGATION	16.1290	0.0620	0.3985	6.426	4.465	28.692
91	EMERGENCY EQUIPMENT	138.8889	0.0072	0.0163	2.264	0.518	1.173
97	EXPLOSIVE DEVICES	2500.0000	0.0004	0.0017	4.333	0.028	0.121
	TOTAL SYSTEMS =	0.4190	2.3866	11.1574	4.675	171.837	803.341

The C-5A's approximately 803 unscheduled maintenance manhours for a hypothetical 72 hour space mission can be compared with the orbiter's projected expenditure of 558 unscheduled maintenance manhours for a mission of the same duration. One orbiter mission of 72 hours will require about 70% of the unscheduled maintenance manhours that a C-5A theoretically would require for a 72 hour space mission. Considering the relative sizes, weights and complexities of the orbiter and the C-5A, this result seems reasonable.

Landing gear maintenance needs were derived directly from the USAF C-141 transport. USAF's DO56 reported experiences (from over 181,000 C-141 landings) were converted to unscheduled maintenance actions, failures and removals per landing, and then used as the per-landing values for the orbiter. For the C-141 the Mean-Time-Between-Maintenance (MTBM) for landing gear was reported to be 5.04 hours, but for the orbiter it will be 226 hours. This significant difference is due to the fact that the average C-141 flight is 1.57 hours while the orbiter's average flight duration will be 72 hours. (The C-141 and the orbiter both experience the need for unscheduled maintenance on the landing gear approximately once every 3 landings, on the average). For the booster, maintenance actions, failures and removals were adjusted downwards due to the simpler and lighter landing gear system planned. Booster landing gear MTBM will be only 1.4 hours however, due to the booster's mission duration of only 15 minutes. This converts to a need for unscheduled maintenance on the booster landing gear once every 5.6 landings (on the average).

Comparable data for DC-8 landing gear experiences was not available from airline sources. The USAF accounts for every manhour expended, thus the DO56 reported information includes all the unscheduled maintenance conducted. Airlines are not required to maintain elaborate maintenance data collection systems such as the USAF's DO56 system, thus airline-reported maintenance data must be used with care.

5.2.3 Main Engine Reliability Analysis

SSME-derivative engines are planned for both the orbiter and booster. A reliability analysis of the proposed derivative engine was conducted to provide data for operations, maintenance and logistics planning purposes. Data for the reliability analysis was extracted from Rocketdyne's document entitled "SSME RELIABILITY DETERMINATION", March 31, 1990. Moreover, this data provided important physical relationships for incorporation in the continuously evolving MAtrix R/M Model.

Figure 5-2 illustrates the effect that SSME thrust levels have on SSME in-flight shutdown rates. Note that at 104% thrust the in-flight shutdown rate is about 2.8 times the rate at 100%. At 109% thrust, the rate of shutdown is about 17 times the 100% rate. The degree of sensitivity to thrust level is significant, especially at 104% and above.

Figure 5-3 depicts Cluster Reliability of SSME engines as a function of thrust level and quantity of engines per cluster. Burn times of 490 seconds were used for each of three cases plotted. The cases plotted are:

- Four (4) of five (5) SSME-derivative engines required (AMLS Baseline).
- Five (5) of five (5) SSME-derivative engines required.
- Three (3) of three (3) SSME engines required (current Shuttle Orbiter).

Assuming that the SSME-derivative engines planned for use on the orbiter are equal in reliability to today's SSME engines, a high order of reliability will be realized since only 4 of 5 are required for AMLS orbiter and booster mission success.

Figure 5-4 was developed using the same SSME data used in preparation of Figure 5-3. In this instance, however, burn times of 120 seconds were used for all cases. Assuming that the SSME-derivative engines planned for use on the booster are equal in reliability to today's SSME engines, an exceptional degree of reliability will be realized since only 4 of 5 are required for mission success. The Shuttle-Orbiter's SSME reliability (for a 120 second burn) is shown (3 of 3 required).

Derivative SSME engines will probably be even more reliable than today's SSME engines, therefore the Figures 5-3 and 5-4 orbiter and booster SSME-derivative engine reliability projections are conservative.

Figure 5-5 depicts overall Launch Reliability for combined orbiter and booster SSME-derivative engines. Included are orbiter engines with burn times of 490 seconds, and booster engines burning in parallel with orbiter engines for 120 seconds. All data plots are based on at least 4 of 5 engines per vehicle operating without critical failure. The Combined plot is the mathematical product of the individual orbiter and booster plots.

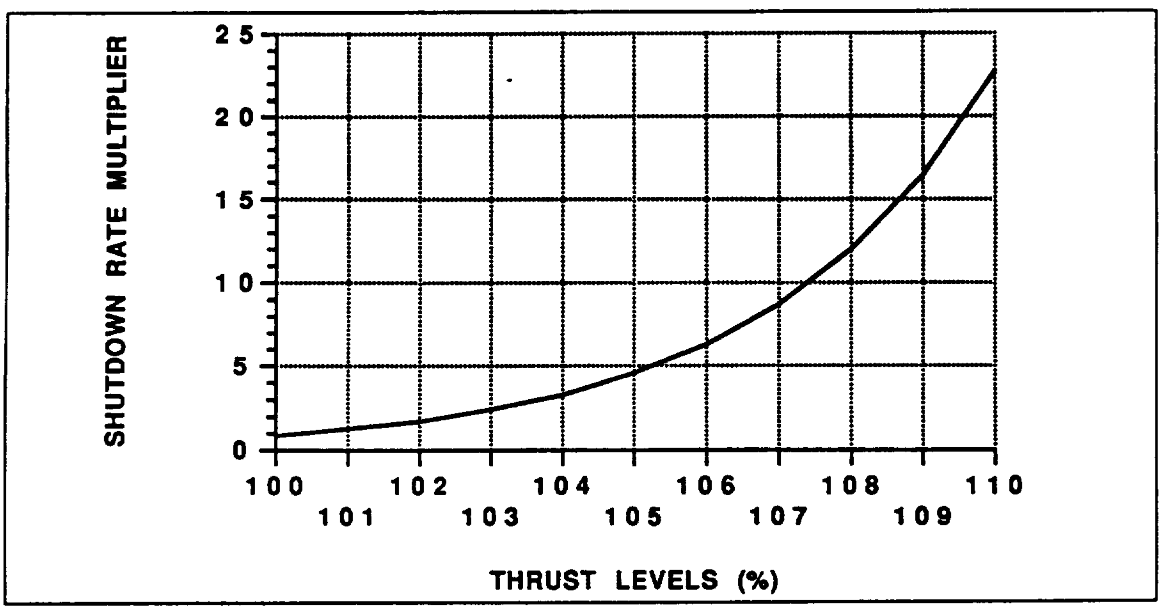


Figure 5-2. Relative Shutdown Rates vs. Thrust Levels.

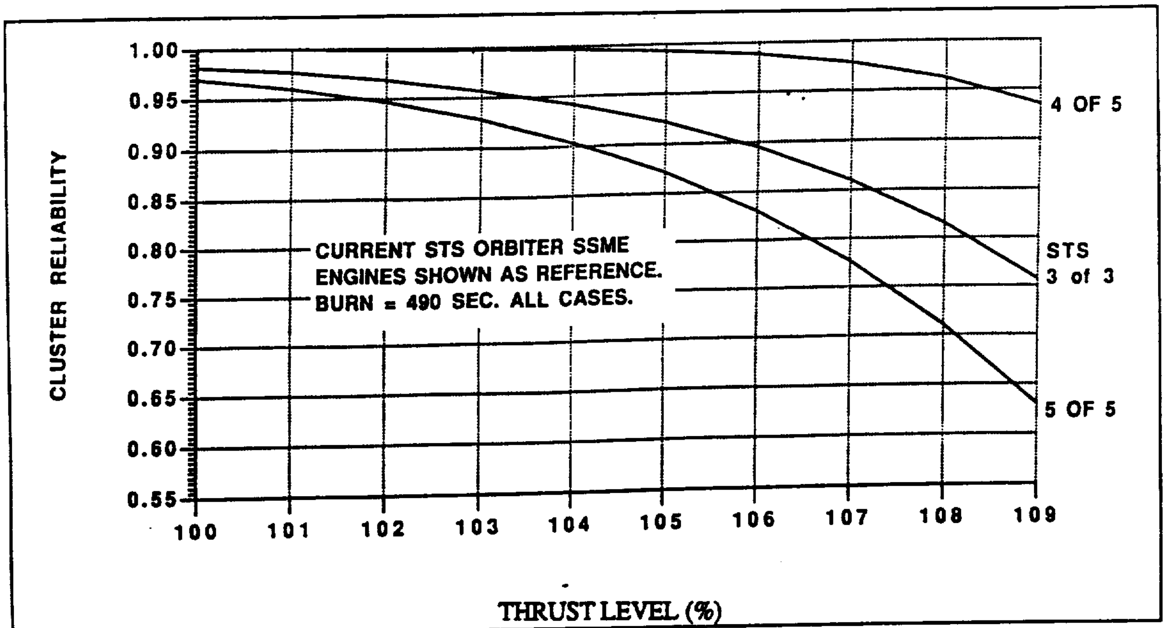


Figure 5-3. Orbiter Engine-Out Capability Assures High Reliability.

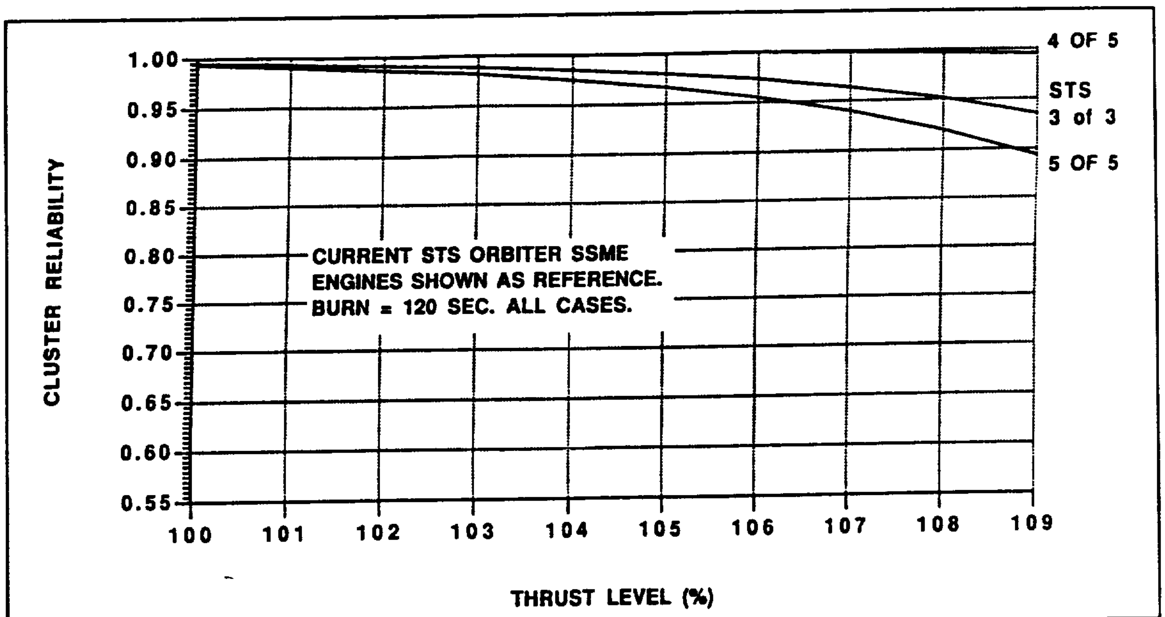


Figure 5-4. Booster Engine-Out Capability Assures High Reliability.

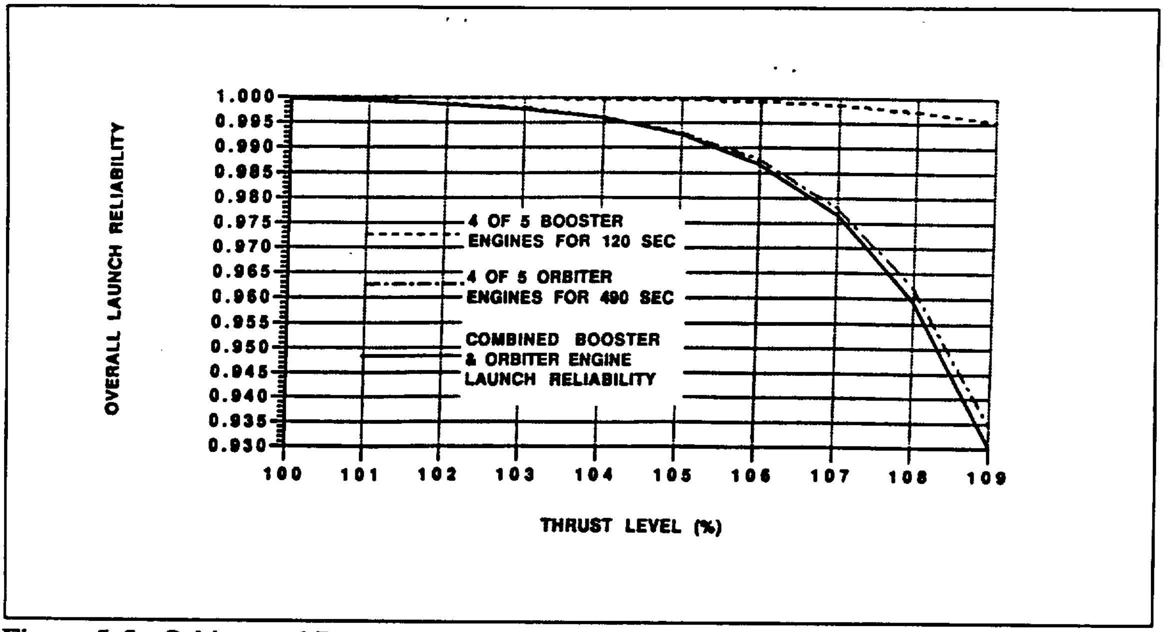


Figure 5-5. Orbiter and Booster Engine-Out Capability Assures High Reliability During All Launch Phases.

5.2.4 Mission Completion Success Probability Analysis

Recently developed algorithms within MAtrix provide for the estimation of MCSP (Mission Completion Success Probability). MCSP is a measure of each vehicle's ability to conduct its planned mission and return safely and uneventfully to earth. Combined MCSP is the product of orbiter and booster MCSPs. Combined MCSP is the probability that on a single mission the booster and the orbiter will both safely and uneventfully return to their designated landing sites after successfully completing all mission objectives. Mission aborts due to other than vehicle-created causes (weather, crew incapacitation, etc.) have not been considered.

MCSP is a function of two key parameters, Mean-Time-Before-Critical-Failure (MTBCF) and mission duration. MTBCF, used in conjunction with mission time, uniquely determines Mission Completion Success Probability (MCSP) according to the relationship:

$$MCSP = e^{-\text{Mission time} / \text{MTBCF}}$$

To put MTBCF into perspective, actual MTBCF achievements for a range of contemporary USAF aircraft are delineated in Figure 5-6. Figure 5-6 illustrates the MCSPs which result for given values of MTBCF and mission time. Note that mission times are in the range of 1 to 2.4 hours, and that MTBCFs are 1,000 hours or less, and that the resultant MCSPs are 0.99+. For the USAF aircraft cited, the overall rate of critical failure averages 0.52% of the reported hardware failure rate (i.e., 1 failure in 200 is mission critical).

To realize an MCSP of 0.99+ for a 72 hour mission the MTBCF must be at least 7,000 hours. The best reported MTBCF for aircraft was 1,042 hours (B-52G/H). A dramatic improvement is required to achieve the 7,000 hour MTBCF required for an MCSP of 0.99. For spacecraft, however, a number of factors help. The space environment, once orbit is achieved, is appreciably more benign than is the aircraft environment. This fact alone results in an improvement in component failure rate by a factor of 2 - 16, depending on the duration of the mission.

Table 5-6. MTBCFs for a Range of Contemporary Aircraft

AIRCRAFT	MISSION TIME	MCSP	MTBCF (HOURS)
F-15C	1.33	0.9979	633
B-52G/H	2.40	0.9977	1042
C-0141A/B	1.60	0.9976	666
C-5A	1.68	0.9955	372
F015A/B/D	1.29	0.9946	238
OV-10	1.01	0.9935	155
B-1B	0.87	0.9928	120
A-10	1.77	0.9921	223
FB-111A	1.90	0.9890	172

MCSP has been estimated for each vehicle. The range of MCSP values estimated for the orbiter represent the range of technically feasible numerical values which result from specific avionic redundancy assumptions. MCSP estimates for the orbiter and booster are as follows:

Orbiter = 0.9688 - 0.9907
Booster = 0.9973
Combined = 0.9662 - 0.9880

Figure 5-6 illustrates how Mission Completion Success Probability varies as a function of the amount of avionics redundancy provided. Separate curves are shown for the orbiter and the booster. Four different avionic redundancy configurations were examined, for each vehicle, using the MAtrix Model. These cases are:

- No redundancy. A single LRU per Avionic System was assumed and that single LRU was required to function for mission success.
- Baseline. Redundancy levels varied by system
- Single fault tolerant.
- Two fault tolerant.

The effects of redundancy are clearly illustrated on Figure 5-6. For the booster, the MCSP improvement as redundancy is added is slight compared to the effect on the orbiter. The sensitivity, or lack thereof, is due to the significant variations in mission time and Main Engine burn times.

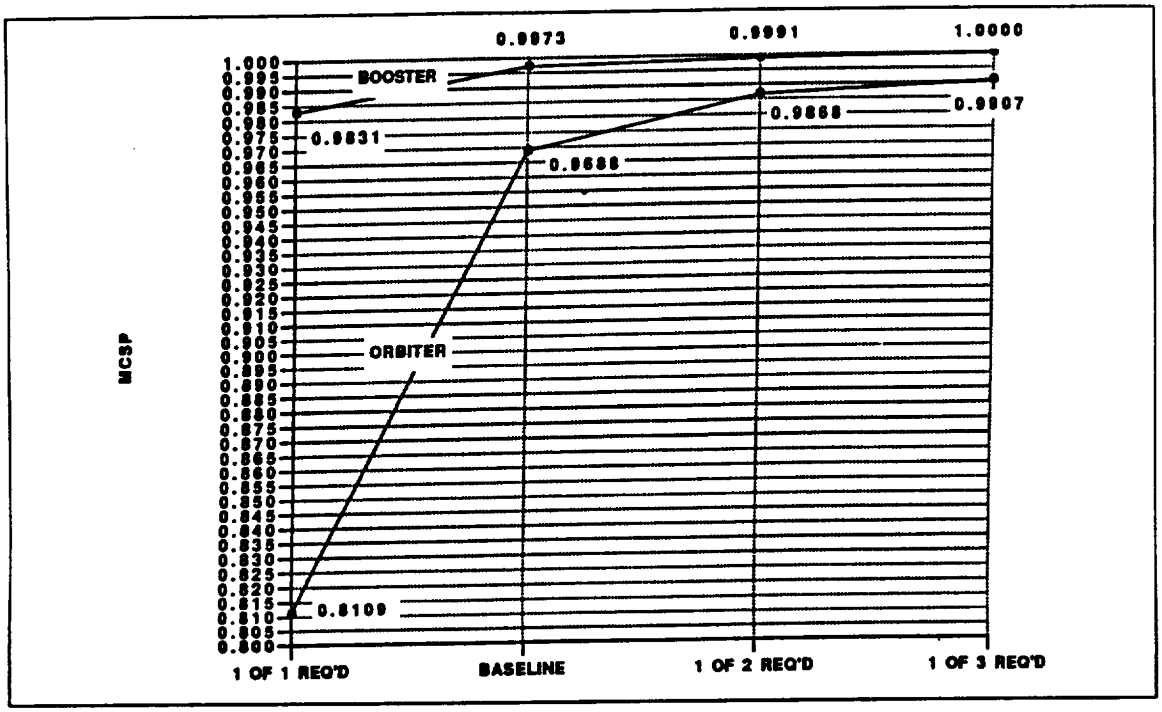


Figure 5-6. How Redundancy Effects MCSP.

5.3 GROUND OPERATIONS

The ground operations analyses to determine the ground operational scenario and supporting facility, software, GSE, manpower estimates, and timelines were performed by Rockwell and Johnson Controls teams at Downey, CA, and Cape Canaveral, FL. The processing approaches were analyzed using an airline approach to ground processing, verifying only those systems on which routine and non-routine maintenance was performed.

As baselined for the PLS, Air Transport Association (ATA) specifications should be adopted and used for the development of technical documentation, allowing a common standard system identification process for drawings, manuals, work documents, and other technical data.

A continually updated maintenance specification, controlled at the launch site with NASA concurrence, will baseline all maintenance and inspection requirements. Specification changes will be based on actual operating experience and trend analysis. Computer based work instructions consisting of work cards support the detailed, accurate, complete manuals. The use of highly trained and experienced A&P

technicians will improve work quality and permit more responsibility and accountability at the source of the work.

5.3.1 Ground Rules and Assumptions

The major ground rules and assumptions followed while performing the ground operations analysis include the following:

- Aircraft-like techniques and methodologies
- Ease of access for maintenance and inspections
- KSC primary launch and landing site
- All unique AMLS facilities at the launch site are new
- Vertical lift off
- On-pad evacuation of AMLS within 3 minutes
- Common propellant for all AMLS propulsion systems
- Modularized PCS with customized PCS's for alternate DRM's
- Late payload access for minimal service at the launch pad (not nominal, but payload option)

5.3.2 Fleet Sizing Analysis

Fleet sizing analysis provides the definition of the fleet size that will have to be produced during the manufacturing production run. The analysis is based on the traffic model in DRD 2 and review of the Civil Needs Data Base (CNDB) for compatible payload for the AMLS program. The results shows the need for a five system fleet size to support up to ten flights per year between the year 2010 to 2040.

Traffic Model Assumptions and Definition. In order to use the Space Transportation Architecture in the traffic model analysis (Figure 5-7, provided by LaRC at the November, 1990 kick-off meeting), the following assumptions need to be stated:

- An alternate manned access to space exists, like a PLS.
- A heavy lift launch vehicle exist, like ALS or NLS.
- SSF crew exchange is part of cargo mission (no missions added to accommodate a SSF crew rotation requirement)
- AMLS is the Shuttle replacement for up and down cargo and crew exchange.
- Other forms for access to space were not considered, like NASP, NDV or SSTO.
- All CNDB payloads that were within the AMLS capability were used to establish flight rate.
- No DoD payloads were addressed in the analysis.
- The AMLS transition start point is the year 2010, with shuttle retirement in 2020.

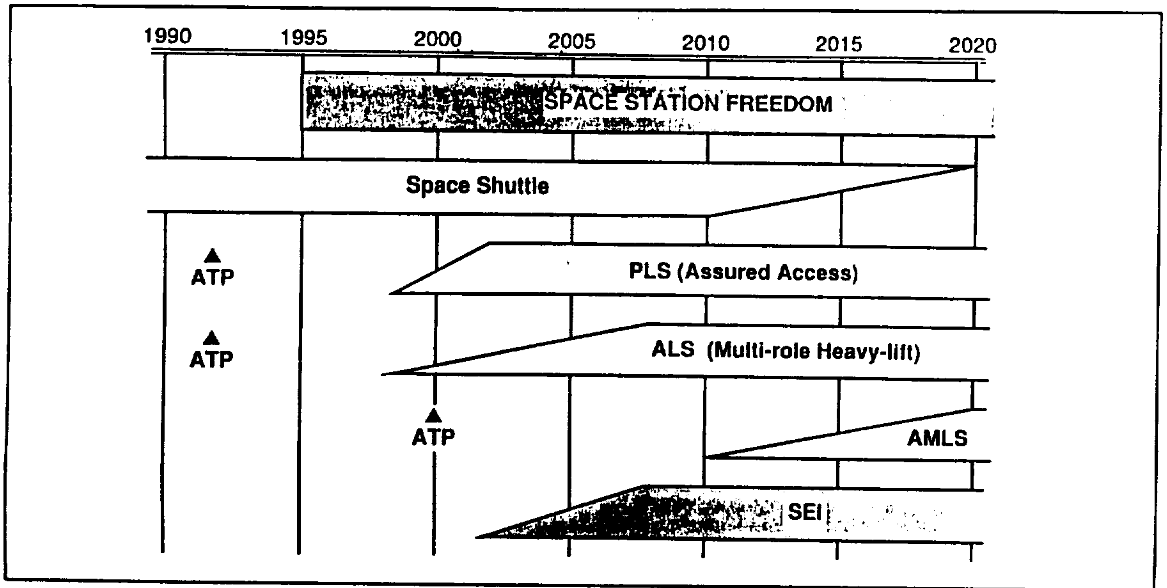


Figure 5-7. Space Transportation Architecture Option.

The CNDB was enhanced to include required servicing missions for the years beyond 2011. These additional missions were created by adding the repeating servicing event patterns between 2001 and 2010 to the CNDB mission model between 2011 and 2020. This increased the total number of events in the mission model by approximately 30%. Long payloads, geosynchronous and bulk propellent transfer missions were eliminated from consideration by AMLS. All down payload would be handled by AMLS beyond 2020.

The average payload length was determined for remaining payloads in the CNDB. Total length was calculated by multiplying the total payload events for each program by the payload length. The sum of program total lengths was then divided by the sum of all events in which a delivery length was defined (a large number of programs in the CNDB do not have any dimensions listed). This process yielded an average length of 9.5 feet. The average number of payload events (with dimensions) per year was 24, with a standard deviation of 6. With a payload bay length of 30 feet, three average payloads per flight can be accommodated. Therefore, from a payload length perspective, the AMLS flight rate is estimated to be 8 ± 2.

Payload mass flow for all non-excluded payloads was summed and divided by the AMLS capability to LEO, due east from KSC. This capability was used since only one event in the data base has an inclination greater than 28.5 degrees between the years 2010 and 2020. Average annual mass flow is 328.5K pounds with a standard deviation of 25.8K pounds, providing an estimate of 9 ± 1 flight per year.

These estimates can be increased by adding manifesting inefficiencies or by a more detailed manifesting approach. One approach to adding manifesting inefficiencies is to limit the maximum number of average payloads to two per flight changing the rate from 8 ± 2 to 12 ± 3. A second is to limit the mass manifesting approach to 80% of capacity. This would change the mass estimate rate from 9 ± 1 to 11 ± 1. For the Task 3 study, a flight rate of ten flights per year was selected.

Fleet Sizing Using Vehicle Loss Rate. The fleet sizing analysis was performed with an assumed reliability of 0.990. Ground operations can support ten 72 hour missions per year with one flight system, satisfying the CNDB analysis above. A second flight system would be needed to support cargo missions to station in case of an contingency.

System Attrition. The traffic model (ten flight per year) would have AMLS support a ten year transition a the beginning of the flight program and five years transition at the end of the flight program, a total of 150 flights with 75 performed by AMLS. Fifteen years of full AMLS operations would add another 150 flights, for a total of 225 flights. Based on an assumed loss of one flight system per one hundred missions (reliability of 0.990), three additional flight systems would be needed to support attrition. The total fleet size would be five flight systems.

Flight probability. The initial approach was to fix the flight rate at 2.5 flights per year per launch system (Figure 5-8). Also, the new vehicle delivery schedule was one new launch system per year. This analysis resulted in a maximum flight rate of 11.8 per

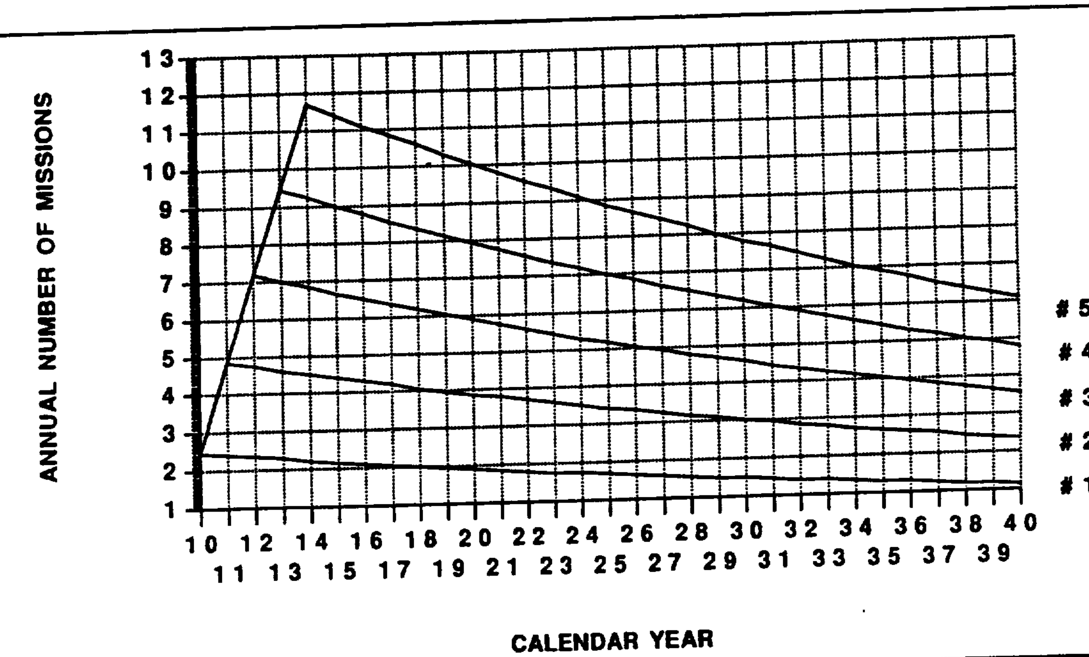


Figure 5-8. Traffic Model with Constant Flight Rate.

year in the fifth year, reducing to 6.1 flights per year in the 30th year.

Then an iterative analysis approach was used which allowed the flight rate per launch system to be increased to maintain 10 flight per year (Figure 5-9. The annual flight rate per launch system was increased when the desired traffic model (shown in dashed lines) was approached. The steps in flight rate (Fight 5-10) were large and the flights performed exceeded the traffic model total by 11 flights. The flight rate at the end of 30 years was 3.5 flights per year per system. At the end of 30 years only 2.64 AMLS systems remained, thus satisfying the initial requirement of two vehicle available to support all contingencies.

Evaluation of the data in Figure 5-10 shows that a flight system would be considered lost when the remaining fleet flight rate exceeds 2.5 and 3.33 flights per year or one flight system loss every ten years. These system losses would not necessarily be catastrophic failures with loss of crew, but could be loss of a booster and/or orbiter with safe escape and recovery of the crew.

AMLS fleet size. The AMLS fleet size consists of five flight systems (five orbiter and five boosters). A future trade and analysis may determine that five orbiters can be supported with less than five boosters. Beyond the year 2020, the AMLS will be the only means of down cargo as shown in Figure 5-7.

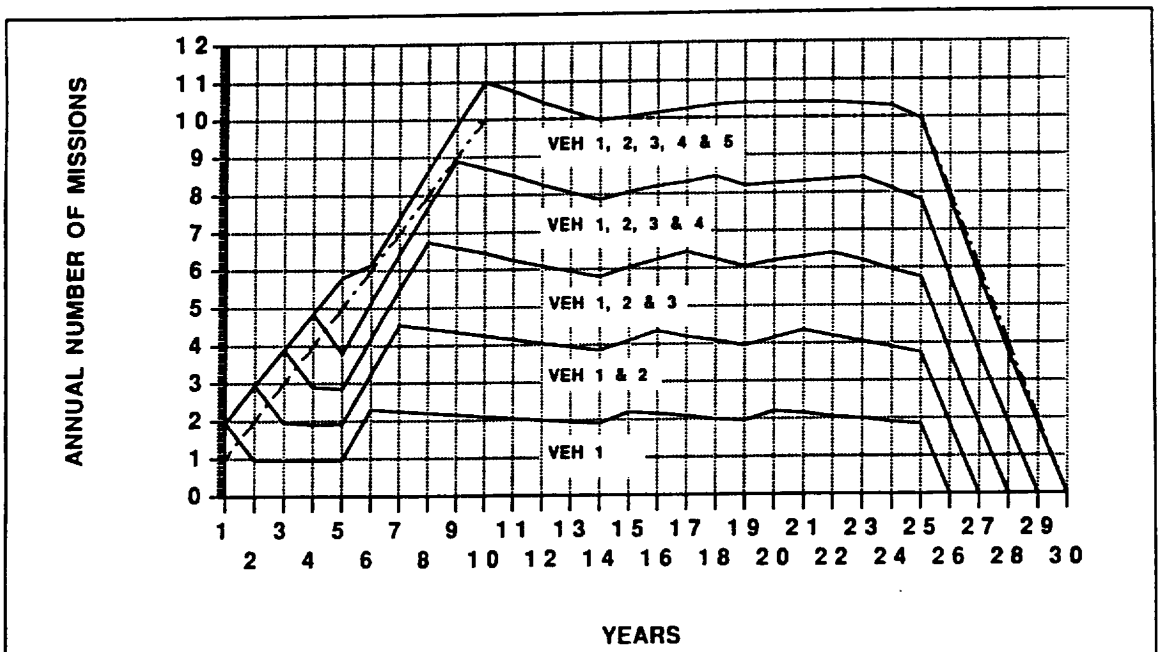


Figure 5-9. Traffic Model with Iterative Flight Rate.

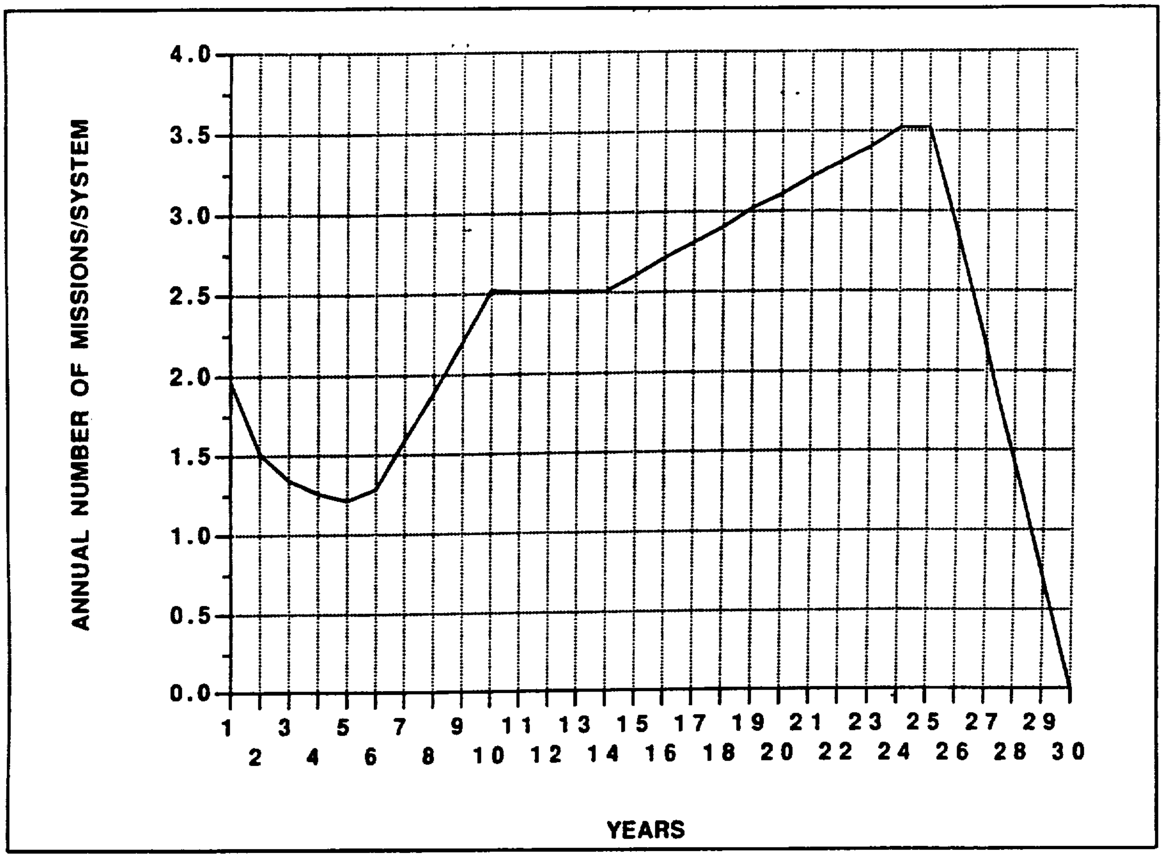


Figure 5-10. Annual Number of Missions Flown per Surviving Flight System.

5.3.3 Operational Scenario

The operational scenario (Figure 5-11) features:

- Horizontal processing of orbiter, booster, and PCS elements
- Horizontal integration of the booster to transporter, orbiter to booster, and PCS to orbiter
- Separate processing, storage, and integration facilities for the orbiter and booster elements
- Vehicle rotation to vertical at the launch pad using an inplace erection mechanism.

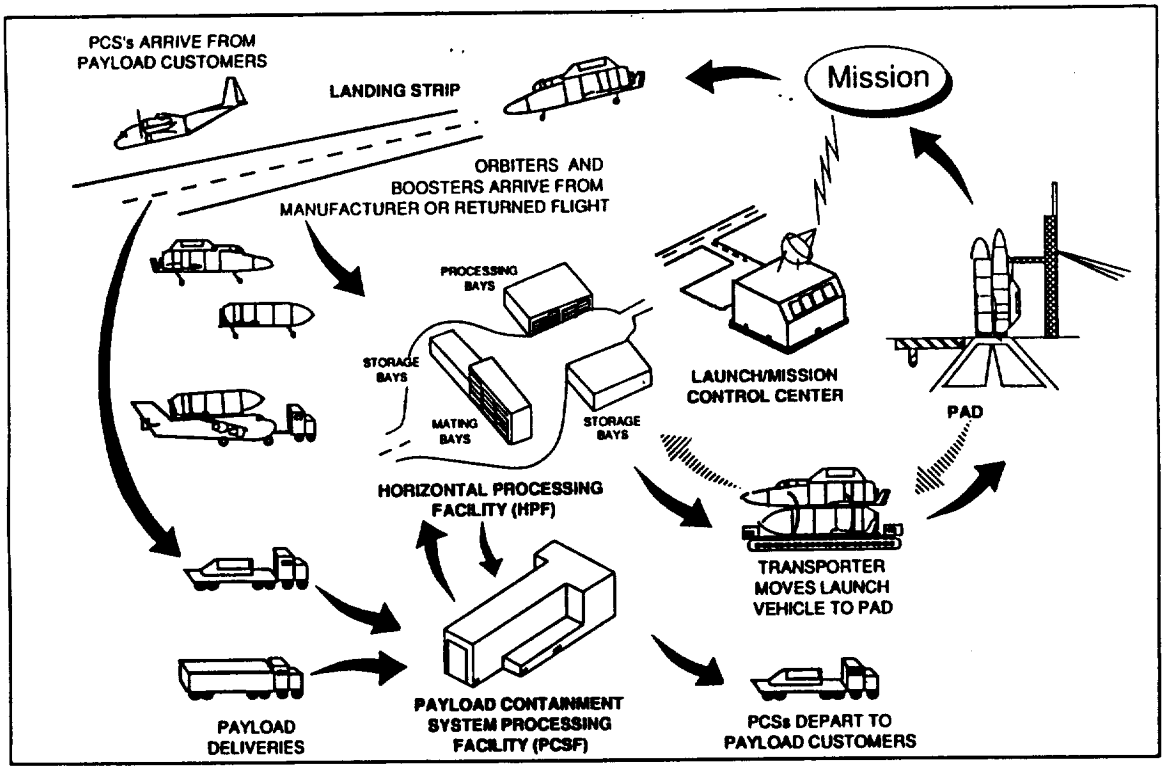


Figure 5-11. AMLS Processing Scenario.

The orbiter and booster elements arrive at the launch site landing strip from a returned mission or from the manufacturer on a carrier aircraft. Elements returning from a mission are towed on their landing gear to the Horizontal Processing Facility (HPF) processing bays. Elements arriving from the manufacturer are towed to the HPF mating bays for removal from the carrier aircraft before they too are transferred to the processing bays.

Elements will undergo processing operations indicated by on-board health monitoring flight data. After preparation for integration with the other AMLS elements, the elements are towed to either a mating bay or to a storage bay.

Integration of the AMLS vehicle will begin with the positioning of the transporter in a mating bay. A booster element is moved into the center mating bay, is lifted and transferred over the waiting transported, and is lowered and mated to the transporter. Next, an orbiter element is then positioned next to the booster/transporter, lifted, transferred, and mated to both the booster and the transporter. A PCS, which has undergone checkout and verification in the PCS Processing Facility (PCSPF) is then lifted and mated to the orbiter. The PCS mating operation is the final operation performed before the AMLS vehicle is transported to the launch pad. This minimizes the time the payload can not be accessed.

The vehicle is transported to the pad, where the supporting structure of the transporter is mated to the in-place erection mechanism. The lower motor units of the transporter are unconnected, and the erection mechanism is used to rotate the vehicle to vertical. After umbilical and interface connections are made and the vehicle is hardmounted to the pad, the transporter structure is returned to its horizontal position. The motor units are re-attached, and the entire transporter is removed from the pad area. Operations at the pad are minimal and will include propellant loading, pyro arming, and crew ingress.

Pad stay time will be minimized to approximately 18 hrs (less than 2.5 calendar days with 1 shift operation), including translating the vehicle to vertical. Access to payloads at the pad will be limited to access to the outer PCS shell where operations such as battery change out may be performed. Payload operations will not be considered a "normal" operation.

5.3.4 Operational Timelines

Timelines representing mature operations were developed for the major AMLS elements: Booster, Orbiter, and PCS. The timelines were defined based on: 1) design characteristics, 2) R/M maintenance estimates, 3) STS experience in determining manpower and resource requirements, and 4) AMLS manhour and technician estimates. The level of technical personnel (by skill type) required to handle rapid turnaround was minimized. The timelines were used to develop probable technician and manhour requirements.

Timelines were based on a single shift, five day per week schedule. Use of two or three shifts or an extended work week would decrease the time period required for processing.

Booster Timeline. Booster processing can be accommodated in 18 days (24 calendar days) in a single shift operation. The timeline presented in Figure 5-12 illustrates booster processing from return from mission through processing and mate to the transporter. Landing site operations are completed in approximately 2 days, including 12 hours provided for propellant venting. Fifteen days (21 calendar days) are required for booster processing, and 1 day is needed for mating the booster to the transporter in the HPF mating bays prior to orbiter mating operations.

Orbiter Timeline. The integrated vehicle timeline presented in Figure 5-13 illustrates a 33 calendar day (25 working days), 8 hours per day, processing flow beginning with orbiter return from a mission through processing, integration, and launch. The flow was developed to accommodate ten launches per year using one vehicle and normal processing.

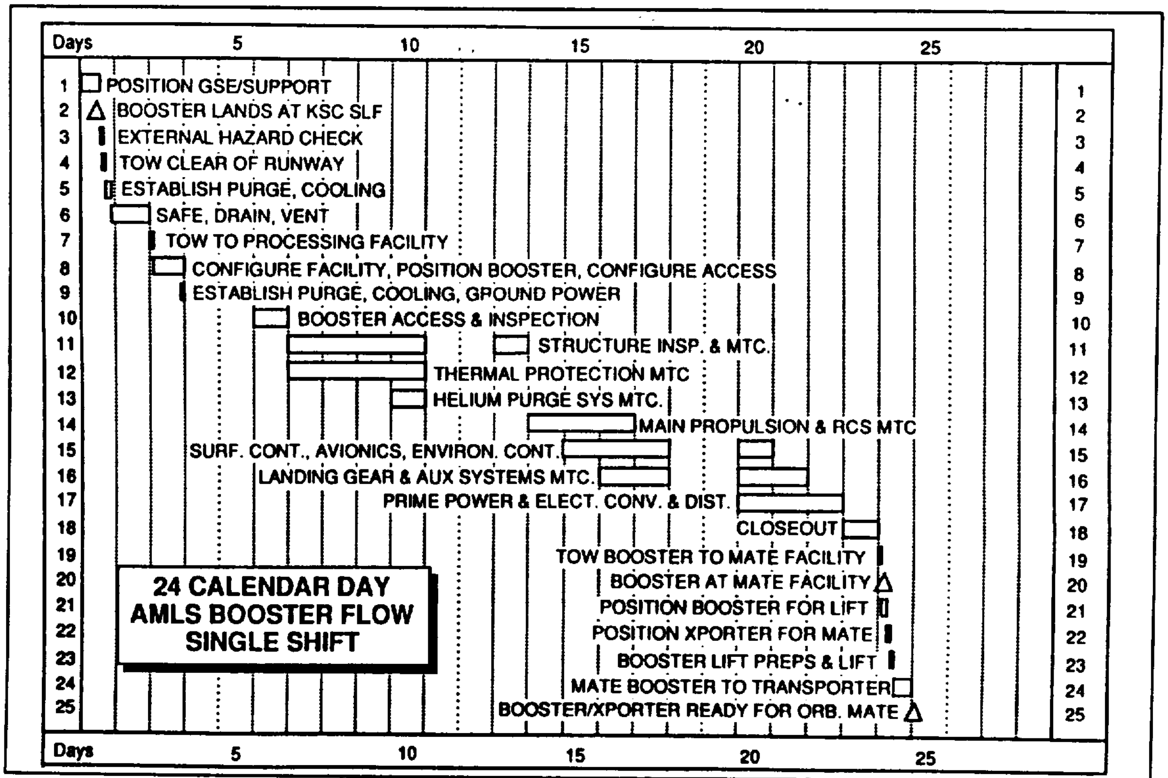


Figure 5-12. Booster Timeline.

Approximately 24 calendar days (16 working days) are required for orbiter processing in the HPF. Mating operations in the HPF mating bays are completed in approximately 6 calendar days (4 working days). Approximately 2.5 days are required for vehicle operations (including transport) at the pad. The two days shown erecting the AMLS on the pad includes eight hours for pad preparations prior to vehicle arrival. The timeline depicts pad activities using the single eight hour shifts; however, it is likely that three shift operations would be used, reducing vehicle pad stay time to approximately 18 hours.

Payload Containment System Timeline. The timeline detailing the operations required to process a PCS from a returned mission is shown in Figure 5-14. After the PCS has been removed from the orbiter in the HPF and transferred to the PCSPF, approximately 14 days (18 calendar days) are required for payload removal and returning the PCS to its generic configuration. Due to each payload's unique requirements, the time required for installation into the PCS is variable, but not expected to exceed approximately 30 days (38 calendar days).

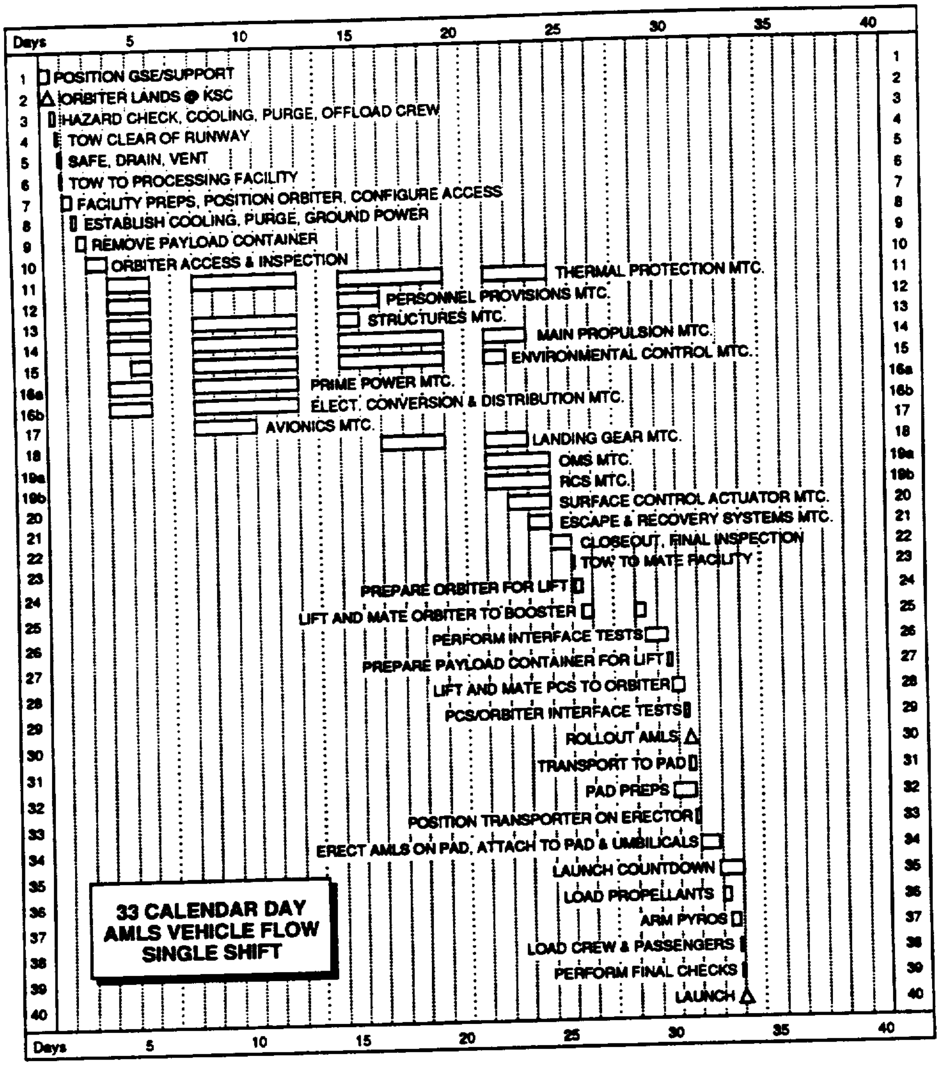


Figure 5-13. Orbiter Integrated Timeline.

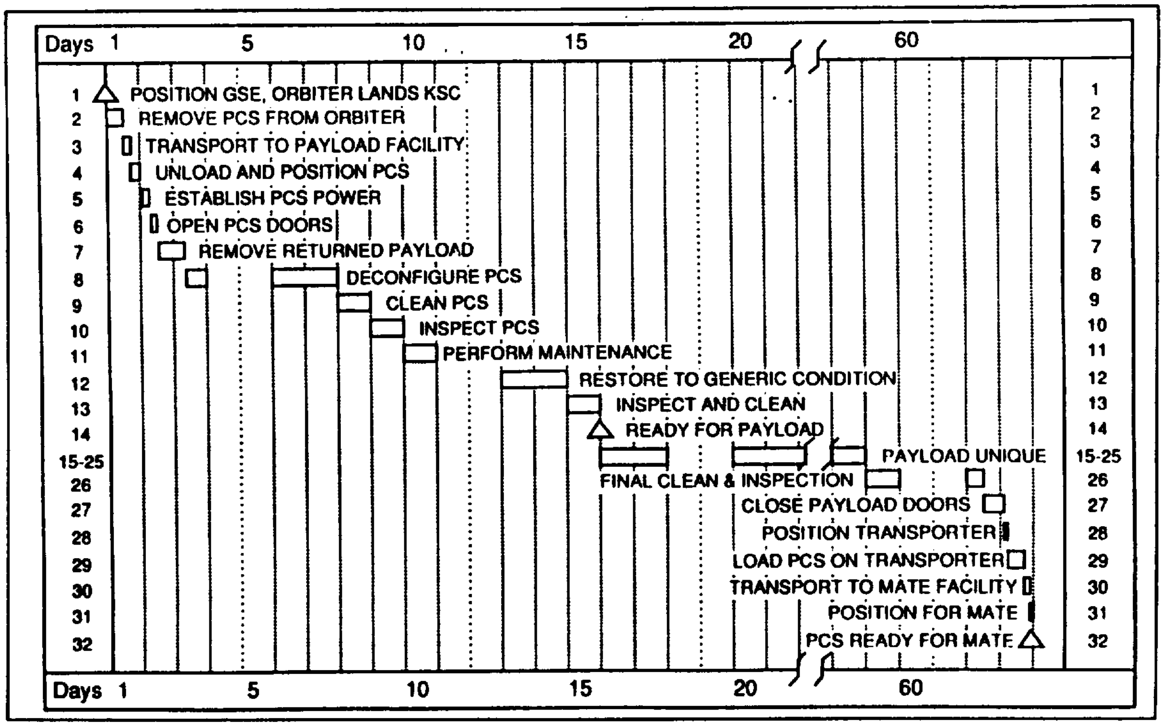


Figure 5-14. Payload Containment System Timeline.

5.3.5 Facilities

Five major facilities (four new) are required for AMLS processing (Figure 5-15). They are the: 1) Shuttle Landing Facility (SLF), Horizontal Processing Facility (consisting of processing, storage, and mating bays), Payload Containment System Processing Facility (PCSPF), launch pad, and Launch/Mission Control Center (L/MCC). These facilities are described briefly below.

Shuttle Landing Facility (SLF). The SLF runway will be used for orbiter and booster elements arriving at the launch site from the manufacturer on a carrier aircraft, as well as orbiters and boosters returning from missions. The landing site may also be used for the arrival of payloads or integrated PCS elements. Boosters returning from a mission are to be towed to the far end of the landing site for propellant venting.

Horizontal Processing Facility (HPF). The HPF will be used for processing, storing and integrating the booster and orbiter AMLS elements. The facility complex consists of three main buildings: Processing (four open bays), storage (four open bays), and integration and storage (three open mating bays adjacent to four open storage bays). The open bay concept permits easy access to the AMLS elements and provides enough room to perform contingency operations. The facility is constructed using conventional building techniques and materials to reduce fabrication costs.

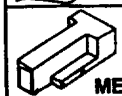
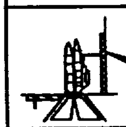
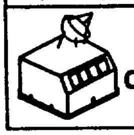
 LANDING SITE	• ORBITER AND BOOSTER ARRIVAL FROM MANUFACTURER • ORBITER AND BOOSTER RETURN FROM MISSION • PCS ARRIVAL FROM PAYLOAD CUSTOMER • PAYLOAD ARRIVAL
 HORIZONTAL PROCESSING FACILITY	• HORIZONTAL (REDUCED FACILITY SIZE/COST/OPERATIONAL COMPLEXITY) - ORBITER/BOOSTER/PCS PROCESSING AND INTEGRATION • REMOVAL FROM DELIVERY AIRCRAFT
 PAYLOAD CONTAIN-MENT SYSTEM PROCESSING FACILITY	• HORIZONTAL PAYLOAD PROCESSING - THREE PAYLOAD TYPES - LARGE PAYLOAD INTEGRATED INTO PCS - SINGLE LARGE PAYLOAD FOR INTEGRATION INTO PCS - MULTIPLE SMALL PAYLOADS FOR INTEGRATION INTO PCS
 PAD	• ERECTION MECHANISM FOR TRANSLATION TO VERTICAL • MINIMAL STRUCTURE (CREW INGRESS/ACCESS TO OUTER PCS) • DUCT ESCAPE SYSTEM WITH SLIDE WIRE BACK UP • NO GROUND POWER
 LAUNCH/ MISSION CONTROL CENTER	• SINGLE FACILITY LOCATED AT LAUNCH SITE • CONSOLIDATED LAUNCH COMMIT CRITERIA • TRAINING SYSTEMS AND RESOURCES

Figure 5-15. Summary Launch Site Facilities.

In addition to normal integration operations, the mating bays may be used for removal of the orbiter or booster elements from the carrier aircraft. Preliminary estimates indicate that approximately 210 working days per year are available for this operation (260 working days per year - 5 days booster/orbiter/PCS integration for 10 flights).

Payload Containment System Processing Facility (PCSPF). Payloads arriving at the PCSPF will be ready for integration into the PCS. The facility will be capable of processing the three types of payloads: 1) PCS with integrated payload(s), 2) Single large payload to be integrated into the PCS container, 3) Multiple payloads to be integrated into the PCS container. Payload processing required at the launch site will be performed in one of the existing payload facilities before the payload is transferred to the PCSPF.

Payloads are checked out and verified before the PCS is transferred to the HPF mating bay. The mating is the last operation performed before the vehicle is transported to the launch pad, minimizing the period in which the payload can not be accessed.

Launch Pad. The pad structures will be limited and will consist of a tower with access to the crew module and to the outer portion of the PCS. A "duct" type escape system (with slide wire backup) will be located on the tower to permit the crew to egress the pad area in less than 3 minutes.

Operations at the launch pad are limited to reduce on-pad stay time for the vehicle. Access to the vehicle will be limited to crew ingress and egress. Payload operations will be permitted, but are not to be a "normal" operation. Battery change out and other operations that can be performed by accessing the outer portion of the PCS will be permitted. Further trades are required to determine the feasibility of denying access to the payload at the pad.

Launch/Mission Control Center (L/MCC). A comprehensive operations concept for the AMLS encompasses launch processing, flight operations, sustaining engineering, and logistics activities. A combined L/MCC supports these functions with a common set of databases, operational tools, and management tools. In addition, a L/MCC at the launch site would separate AMLS crew training from that the for the SSF.

The three story L/MCC, located near the HPF and PCSPF, will provide:

- Launch and Mission control Rooms
- Training simulators, 0-g/1-g trainers
- Ground/launch mission viewing and evaluation rooms
- Software laboratories
- Mission data recording facilities
- Technical Library Support
- Office space for support areas

5.3.6 Manpower Requirements

The detailed staffing levels for mature operations for the orbiter, booster, and PCS were determined based on appropriate STS, airline, and R/M estimating factors. Hands-on technical support and support personnel/management staffing are detailed below.

Hands-On Technical Support. AMLS processing tasks will be performed using highly trained, skilled and disciplined A&P type technicians. Skill categories will include avionics, electrical, thermal protection, and mechanical/system, with cross-training and intensive training in specific skills. Technicians will use technical documentation which is complete, correct, and in ATA format.

The hands-on technicians for combined orbiter, booster, and PCS processing are tabulated in Table 5-7. The table includes the technician requirements for normal processing and major inspection (heavy maintenance type activities). The elapsed times and manhours by skill required to perform the processing activities (Figures 5-12, 5-13, and 5-14) were totaled on a daily basis to determine the total number of technicians required. An additional 12% was added to the total technicians required to account for non-productive time for vacations, sick leave, jury duty, etc.

Table 5-7. Technician Requirements for Processing and Major Inspections.

Skill	Normal Processing			Major Inspection		Nominal	Non Productive	Total Req'd
	Orbiter	Booster	PCS	Orbiter	Booster			
Avionics	2	1	1	3	2	9	2	11
Electrical	3	2	2	5	3	15	2	17
TPS	2	1	0	3	2	8	1	9
Mech/ Systems (includes tank in-sulation /engines)	9	4	4	14	6	37	5	42
Total	16	8	7	25	13	69	10	79

Support Personnel/Management Staffing. The support personnel required for the AMLS were modeled after airline operations with consideration given to spacecraft operations peculiarities. The staffing developed for the PLS Task 1 were evaluated to determine the categories requiring additional personnel to support the AMLS mission. Support personnel are presented in Table 5-8 and include personnel in the following categories:

- Management and secretarial support
- Clerks - finance and accounting, planning, scheduling work control, processing, records, stores, and shipping and receiving,
- Technical writers
- Technicians for AMLS orbiter, booster and PCS processing and facility O&M, communications, and GSE
- Engineers - airframe/systems , avionics/electrical/instrumentation , project, and mass properties
- Quality inspectors
- Safety analysts and specialists
- Programmers
- Logistics buyers/expediters

Search and Rescue Manpower. Two emergency scenarios have been identified in this study:

- Crew emergency after lift-off with the orbiter and booster mated (Figure 5-16)
- Crew emergency after lift-off after booster separation (Figure 5-17).

The ground treatment of the emergency is determined by the ascent flight phase and the nature of the problem (orbiter or booster emergency, crew capsule problem, distance/altitude downrange.

Table 5-8. Support Manpower Requirements.

Office	Personnel
Overhead	
Managing Director's Office	3
Human Resources and Medical	8
Finance and Accounting	12
Site Director's Office	3
Legal/Contracts	4
Production Planning and Control	20
Engineering	37
Processing Operations	
Staff	16
Technicians	36
Major Inspection Operations	
Staff	10
Technicians	43
Quality and Safety	55
Support	46
Logistics	26
Shops	*52
Total	371

* Shop staff supplemented with processing technicians when not utilized for processing.

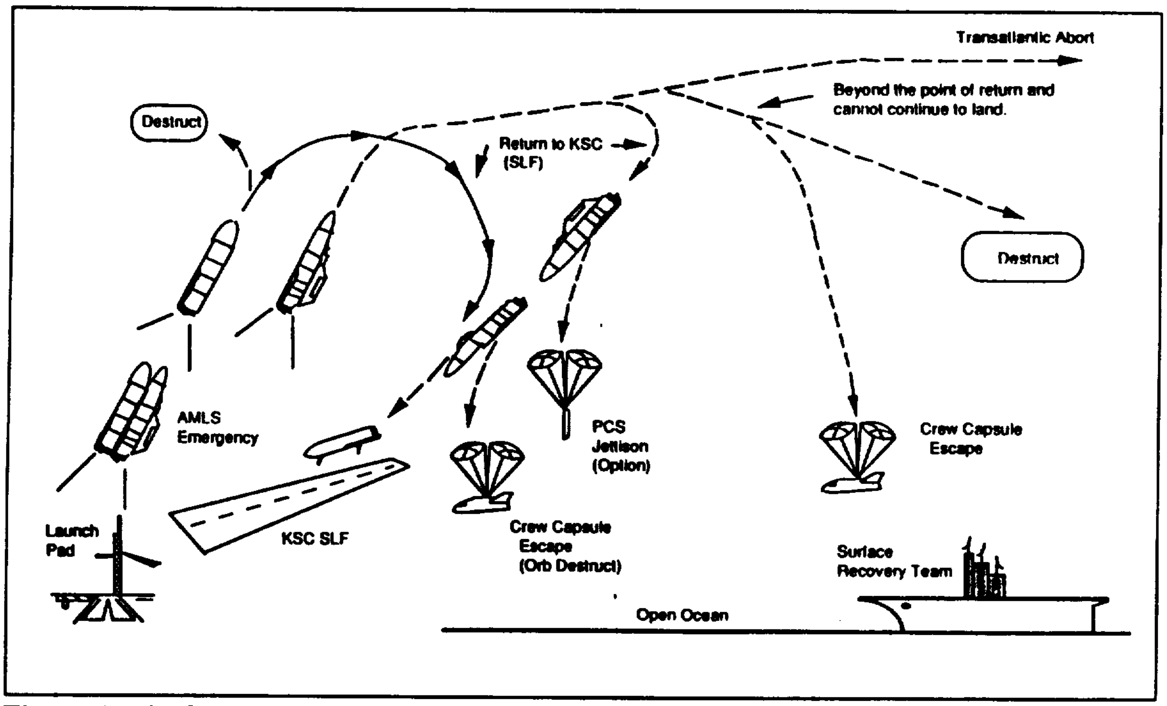


Figure 5-16. Crew Emergency After Lift-off - Mated.

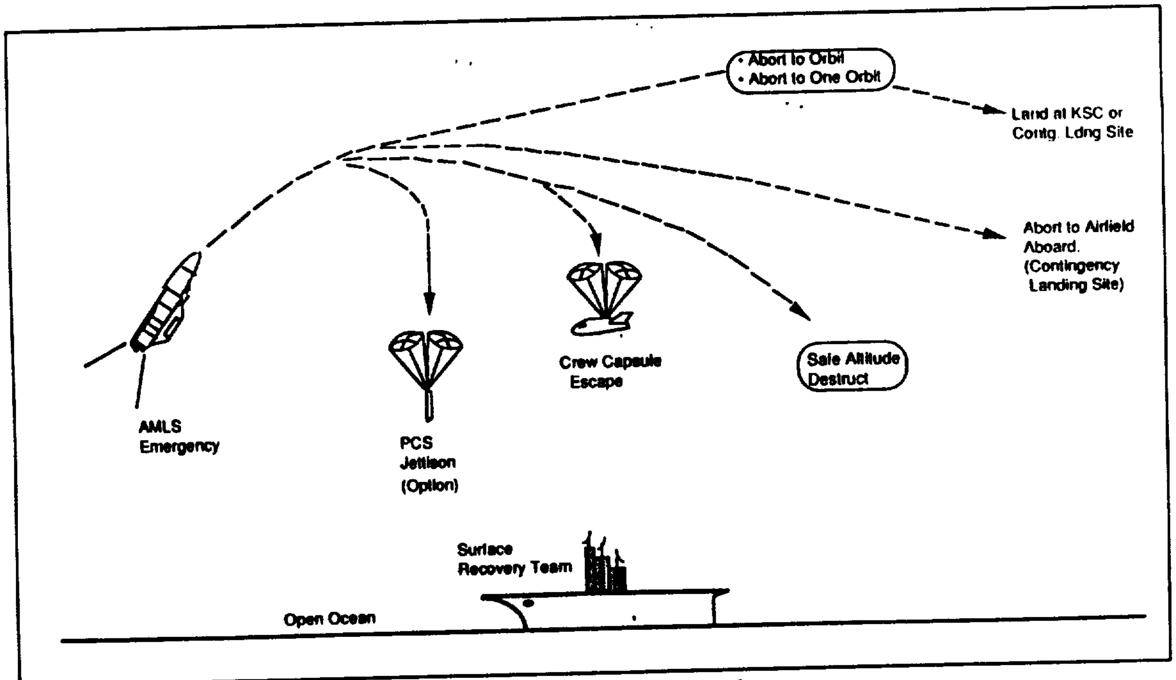


Figure 5-17. Crew Emergency After Lift-off - Demated.

Tables 5-9 and 5-10 indicate when ground and water forces are required for the two emergency scenarios.

The cost and manhours estimates for search and rescue preparation for the STS system versus the AMLS (if performed like STS) versus the AMLS (if performed with airline approach) is shown in Figure 5-18. The manhours required by the rescue team are increased when compared to the STS due to the increased number of personnel in the AMLS vehicle as compared to the STS. There are over 150 possible commercial and military landing sites world wide available to the AMLS as unplanned landing sites. These site will be supplied with a familiarization video briefing (production and distribution costs = $60K) and accompanying documentation (development and production costs = $50K). Personnel at the primary landing sites will receive extensive unplanned landing training. Large cost drivers are detailed in Table 5-11.

Table 5-9. Crew Emergency After Lift-Off - Mated.

	Land Fire/Rescue	Water Fire/Rescue
Booster separation - Booster return to KSC/SLF - Booster destruction in safe area	X	Recovery
Orbiter - Return to KSC/SLF with PCS - Jettison PCS (Option) - Return to KSC/SLF without PCS - Crew abort in Crew Capsule	X X	Recovery Recovery & Rescue
Orbiter return to contingency airport (USA)	X	
Orbiter return to contingency airport (non-USA)	X	

Table 5-10. Crew Emergency After Lift-Off - Demated.

	Land Fire/Rescue	Water Fire/Rescue
Abort to Orbit		
Orbiter return to contingency airport (USA)	X	
Orbiter return to contingency airport (non-USA)	X	
Jettison PCS (Option)		X
Crew abort in crew capsule		X

Table 5-11. Cost Drivers.

	AMLS Like STS	AMLS Like Airline
Pad	\$113K Equip & Mods; \$113K Rescue Equip	\$113K (Same)
Runway	\$522K Rescue Team Equip	\$522 (Same)
TAL	\$1.4 M Rescue Team Equip (3 Sites)	\$110K Training Materials Development
KSC Ditching	\$722K Rescue Team Equip (KSC only)	\$78K: \$38 Rescue Team Equip; \$40K Accident Investigation Kit
Open Ocean Ditching	\$2.2M Rescue Team Equip (3 sets)	\$114K Rescue Team Equip (3 sets)

		STS COSTS Initial	STS COSTS Per Flight	AMLS-LIKE STS Initial	AMLS-LIKE STS Per Flight	AMLS-LIKE AIRLINE Initial	AMLS-LIKE AIRLINE Per Flight
EMERGENCY EGRESS AT PAD	Manhours	240 mhr	200 mhr	336 mhr	200 mhr	336 mhr	200 mhr
	Mods & Equip	\$1,582K	TBD	\$7,213K	TBD	\$113K	TBD
EMERGENCY EGRESS AT RUNWAY	Manhours	144 mhr	111 mhr	240 mhr	189 mhr	240 mhr	20mhr
	Mods & Equip	\$688K	TBD	\$952K	TBD	\$522K	TBD
EMERGENCY EGRESS AT TAL	Manhours	288 mhr	4552 mhr	480 mhr	5520 mhr	6096 mhr	520 mhr
	Mods & Equip	\$656K	TBD	\$2 mil (3 Sites)	TBD (Flt. dep)	\$110K	TBD
CREW RECOVERY IN KSC AREA (TO 200)	Manhours	336 mhr	161 mhr	480 mhr	230 mhr	1540 mhr	254 mhr
	Mods & Equip		\$75K(AF)	\$722K		\$78K	TBD
WORLD WIDE SEARCH & RECOVERY	Manhours	336 mhr	161 mhr	480 mhr	230 mhr	1540 mhr	24 mhr
	Mods & Equip		\$225K(AF)	2.2 mil (3 Sets)		\$114K (3 Sets)	TBD
Total Manhours		1344	5185	2016	6449	9752	1098
Total Mods & Equip		\$2,926K	\$300K+	\$4,957K	TBD	\$937K	TBD

AMLS CREW COUNT REQUIRES MORE GROUND SUPPORT UNDER STS APPROACH

AMLS RECURRING IS LOWER WITH AIRLINE APPROACH

Note 1: STS manhours are KSC EG&G (Base Operations Contractor) Fire & Rescue only.
Note 2: Source of STS and AMLS-like-STS S&R OPS was NASA/STS and EG&G(BOC) Fire & Rescu
Source of AMLS-like-Airline OPS was PAN AM database based on AMLS design capabilities
Note 3: Additional expenses would be accrued in an actual contingency event such as: unique costs, AF transport, local Medical, commercial equipment use, relocation of manpower to support.

Figure 5-18. Search and Rescue Manhour & Cost Estimates.

5.3.7 Ground Software

The AMLS lends itself to a comprehensive operations software concept which encompasses launch processing, flight operations, sustaining engineering, and logistics. Each of the functions would be supported by a common set of databases, operational tools, and management tools. Training resources, flight operations systems, and launch system would all reside within a common complex.

The integrated L/MCC approach allows common operational data to be utilized to support all respective operations phases. The concept reduces the ground support systems, resources, and facilities required to perform the mission objectives. The console configurations for the control center would be a generic baseline which would be configured for specific support functions through software selection and control. This provides ground support system redundancy by being able to support any discipline from any system console by configuration selection.

The launch site/flight operations scheduling would be controlled and managed on an integrated basis and a great deal of crew interface and payload related integration activity (i.e., safety review) could occur at one location. This should reduce the amount of travel required to accomplish these activities (as compared to the NSTS environment.)

The L/MCC will not provide payload support or training. This support will be provided by a remote Payload Operations Control Center (POCC).

A bottoms up estimate of AMLS ground software lines of code (SLOC) (Table 5-12) was made based on the following factors:

- Vehicle telemetry data will be received from both the orbiter and the booster. Even with common avionics, unique measurement identifications are assumed necessary to identify the source of the data.

- The ground network will be tasked with validating vehicle readiness for flight, although this effort will require considerably less ground resources than the existing NSTS because of the on-board design for testability, on-board checkout, and health monitoring capability

5.3.8 Ground Support Equipment

New GSE will be required to support AMLS missions. This GSE includes that required for processing all orbiter, booster, and PCS containers at the landing facility, HPF (processing, storage, and mating bays), PCSPF, and launch pad.

A facility assessment of the GSE required for AMLS ground operations has identified 13 distinct categories of equipment which include tools and test equipment for: 1) gaining access, 2) handling operations, 3) specific system servicing and 4) contingency maintenance. Commercially available "off-the shelf" equipment was identified where possible. The majority of the 183 types of equipment identified are to enable correction of anomalies diagnosed by the on-board health monitoring system.

Table 5-12. Ground Software Summary.

FUNCTION	SOFTWARE (SLOC)
Operating System	Commercial Off-the-Shelf
Maintence Tasks	100K
Vehicle Test Programs	1,600K
Vehicle Meas. Database	300K
Planning, Scheduling, & Status	1.500K
Logistics	Commercial Off-the-Shelf
	600K
Network Interface Software	Commercial Off-the-Shelf
Mail System	Commercial Off-the-Shelf
Payload Containment System	800K
Range Applications	1,300K
Weather	600K
Mission Recording & Post Analysis	Commercial Off-the-Shelf
Launch Management System	1,00K
Software Support	1,300K

Costing estimates are provided for all but seven GSE items. The estimates, derived from a variety of sources, include the purchase price at KSC and the year of purchase. No cost is provided for the 747 ferry aircraft. This aircraft may be purchased new and configured at the manufacturer, or may be purchased used and reconfigured by a contractor. Fairings for the orbiter and booster elements during air transport will be similar in cost and construction to the Shuttle orbiter's fairing.

Two major new pieces of GSE are required by the reference scenario to: 1) transport and support the vehicle, and 2) remove the deconditioned SSF crew from the vehicle at the SLF runway. A horizontal transporter is required to move the mated vehicle to the launch pad from the HPF integration bay. The new transporter concept features a removable cradle used to support the vehicle during translation to vertical at the pad. Four independent computer linked electric drive units at the corners of the transporter reduces spares requirements and simplifies maintenance. Once at the launch pad, the transporter will be mated to the in-place erection mechanism, the motor driven units will be detached, and the structure of the transporter will be used to support the vehicle during erection to vertical. After the vehicle is mounted on the launch pad and the erection mechanism has returned to horizontal, the motor units will be reattached to the transporter support structure and the transporter will be removed from the launch pad.

The transporter can rapidly move the AMLS, reducing weather exposure and processing time. No special crawler way will be required.

Deconditioned passengers must be removed from a hatch in the top of the orbiter at the SLF runway. Two possible approaches are use of a "plane-mate" type lift vehicle currently used at some airports for passenger handling, or a "cherry-picker" type vehicle with sufficient capacity, height, stability, and platform size.

5.4 FLIGHT AND MISSION OPERATIONS

Our approach to flight and mission operations was to develop a standard system for preparing documentation and processes that can be used with minimal update for flights to the SSF. We identified capabilities which could be automated and baselined standardization of functions which would contribute to efficient flight operations support requirements and minimize turnaround time. Standardization and reuse of products will support a short flight preparation cycle and continued assignment of experienced personnel will reduce training requirements.

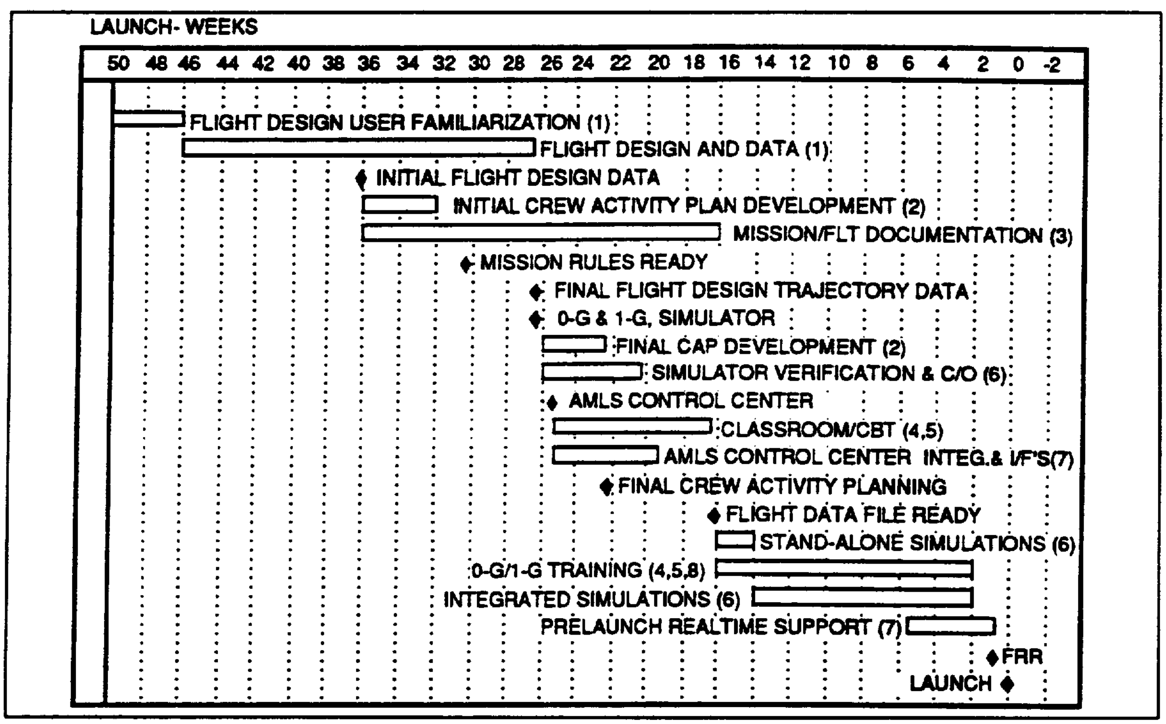


Figure 5-19. Mission Preparation - OFT Flights.

The AMLS baseline mission to the SSF parallels the flight and mission operations previously developed for the PLS, based on the common mission requirements. The data developed from this previous study was evaluated and redefined to provide relevant AMLS data for Orbital Flight Test (OFT) and mature operations flight preparations templates and to provide manpower and facility estimates (Figures 5-19 and 5-20).

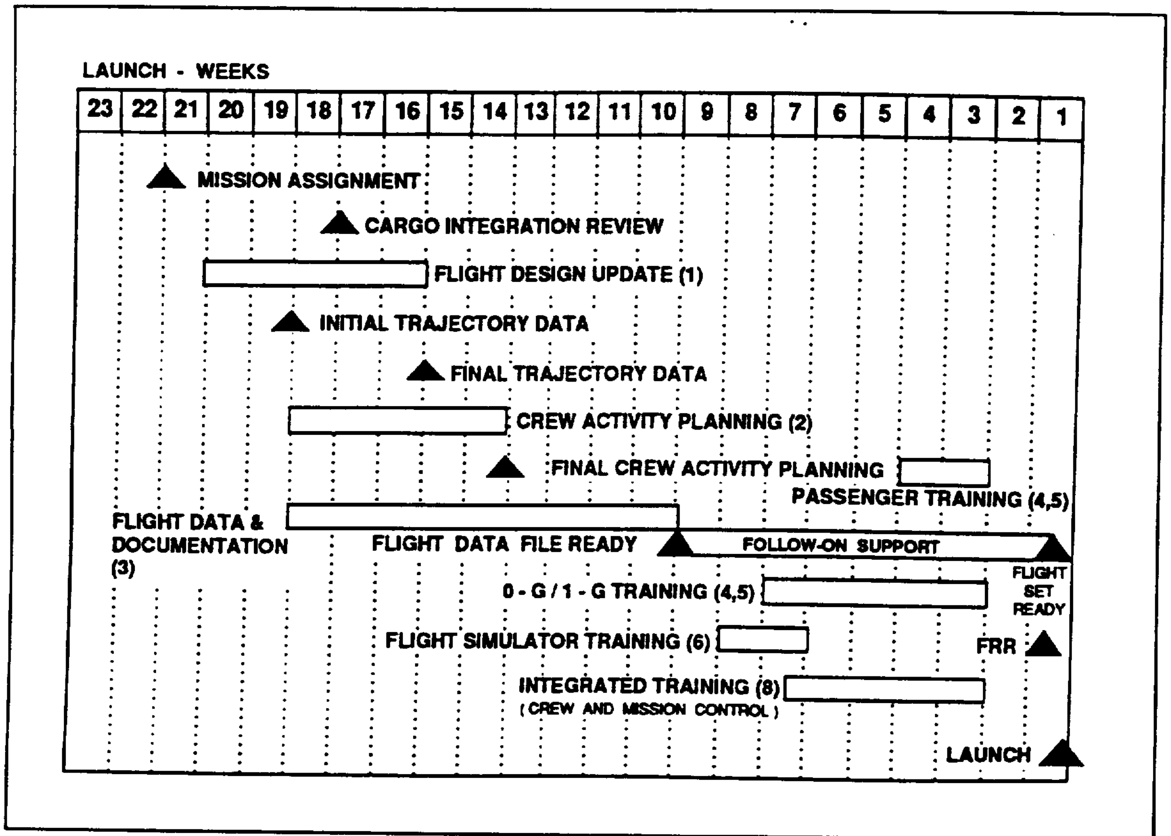


Figure 5-20. Mission Preparation - Operational Flights.

5.4.1 Key Mission Operations Assumptions.

The following key ground rules and assumptions were followed when performing the flight and mission operations analyses:

- Accommodate DRM-1 (without precluding other missions)
- Crew/8 Passengers to/from SSF at 220 NM at 28.5° inclination
- Deliver/return 15' dia. by 30' length payload, max weight 40K lbs
- Booster - unmanned glide back to launch site runway
- KSC prime launch and landing site
- 72-hour mission duration plus 12 hours for contingency
- Payload transfer to/from SSF may require additional hours
- Shuttle orbiter and SSF interface docking procedure used
- Rendezvous sequence based on PLS
- SSF Remote Maneuvering System (RMS) used for payload removal/loading
- New SSF crew performs payload transfer operations
- Standardized - Flight Profile, Flight Operations Sequence, Trajectories, SSF Rendezvous/Separation Sequences, Propellant/Consumables Loading, Procedures/Displays/Formats

Standardization Assumptions. Standardization of the AMLS vehicle flight and mission operations will reduce updates for flight and mission planning, shortening the flight preparation cycle (Figure 5-20). The AMLS will be designed to operate within mission envelopes rather than to specific flight parameters, reducing the requirements for flight redesign from mission to mission. Minimizing the preparation cycle reduces the manpower and facilities required to support the flight preparation activities. The flight design analysis for DRM-1 (SSF mission), once performed and verified, should provide a standard core design that will only undergo minor modification from flight to flight. Variations in payload and SSF/AMLS flight relationship will cause some mass property and timeline variations, but the basic mission profile and sequences will be recurring.

Flight operations functions will be standardized for the AMLS booster and orbiter. The booster re-flight profile will be a standard profile to reach the MECO (Main Engine Cut Off) and separation conditions. From main engine start through fly back and roll out, the sequence of events will occur as a repeatable set.The booster profile envelope should be the same for all DRM-1 flights and should support alternate DRM's within the AMLS requirements.

The flight sequences for all DRM-1 orbiter and booster flights will be repetitive. Some variations in orbiter flight requirements will occur due to payload manifest weight, RMS support activities and emergency EVA (Extra Vehicular Activity) events. The complexity of payload transfers will influence the orbiter on-orbit stay time, impacting the entry phase of the flight. However, after several flights a flight design library would be established to provide a "most like" starting point for future missions, therefore minimizing "design" rework requirements. The propellant loading for the booster can be standardized and therefore the mass properties for flight design can be treated constant for liftoff and center of gravity determination.

The range safety limits which identify safe flight corridors for the AMLS booster and orbiter can be standardized for the powered flight phase and for the booster fly back phase. The number of two engine-out combinations and resulting controllability may have to be treated as a non-standard condition and call for expert system tools for the decision making process.

The flight design analysis for the DRM-1 mission will be accomplished for and verified during the OFT flights and should require only minor adjustments for variations in time and delta velocity as a result of the SSF-orbiter relationship (phasing orbit).

Telemetry and command formats can be established and maintained for the flight systems and ground support system with only sustaining engineering changes resulting in modification to the operational systems for flight design can be treated constant for liftoff and center of gravity determination.

Verification for DRM-1 in terms of flight operations management must occur during OFT. If OFT test scenarios do not validate operational requirements, the system should not transition to DRM-1. System management during orbiter flight phases and the attendant procedures should be validated during the OFT flights and only be subject to maintenance due to equipment changes or upgrades.

Flight Automation Assumptions. A high degree of automated capability must be designed into the AMLS avionics and support systems in order to support the autonomous flight operations concept. Decision making criteria must be developed to define mission phase transition points (i.e., launch to on-orbit, on-orbit to entry, etc. [Figure 5-21]). Development of expert systems within the flight and ground system architecture will be required to support mission execution and provide the flight crew and mission support personnel with the information necessary to perform manual intervention. Abort calls will probably be at the heart of the expert system requirements.

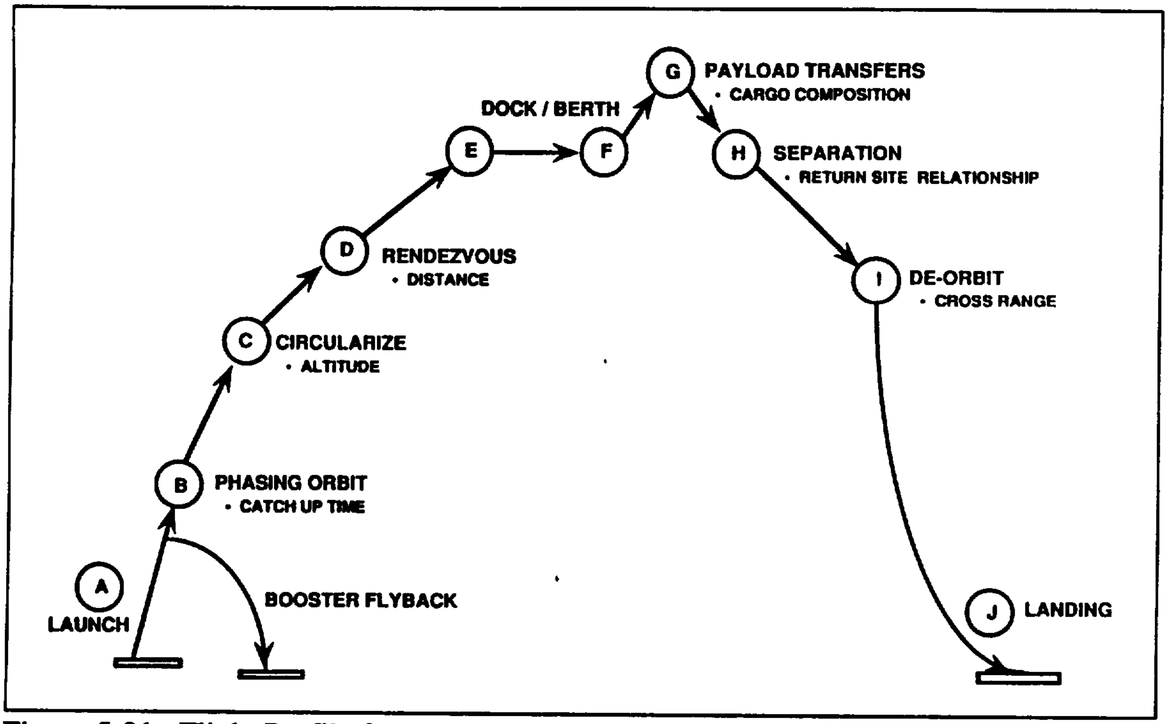


Figure 5-21. Flight Profile for Automation.

Flight Information Management Assumptions. On-board electronic flight documentation will be used for the AMLS missions. This capability will include the procedures, check lists, charts, trajectory data, and graphics. This capability will provide for real time updates or additions through the uplink capability. There will be a certain number of critical items placed on-board in paper form to ensure backup availability.

The health monitoring data will be available to the crew for system management purposes and stored on-board for post-flight evaluation. Critical mission phase health monitoring information will be downlinked to provide real time input in the event of critical phase anomalies.

The depth and dissemination of health monitoring information should be to the level necessary to ensure operational requirements and capabilities are met.

Vehicle communications, which include air-to-ground voice and video, telemetry, uplink command, and GPS reception, will incorporate state-of-the art technology and include provisions for upgrades as technology advances.

5.4.2 Mission Timeline

The mission timeline for the AMLS DRM-1 mission (Figure 5-22) was developed using the ascent, rendezvous and entry trajectory data previously compiled for the PLS DRM-1 "shorter rendezvous" timeline. It has been expanded from 72 to 92 hours for provisions on flight days 3 and 4 to transfer payload cargo to the SSF and to retrieve logistics module(s) from the SSF to the orbiter. The timeline provides liberal times to accomplish the transfers with the AMLS crew awake during these activities. In addition, the timeline assure the flight crew has had adequate rest before the nominal return opportunity. As flights become routine and experience is gained on the actual task accomplishment times, these criteria may change. A shorter timeline must address the crew rest constraint and make a significant reduction to synchronize the conditions. However, as a preliminary baseline for the AMLS DRM-1 mission, it seems prudent to use this criteria to size flight consumables and provisions for the mission.

The SSF RMS will be utilized to extract payloads from the orbiter PCS and to install logistics modules scheduled for return aboard the orbiter. The space station "up" crew will be trained for payload and logistics transfer as part of the space station "increment" preparation. This will also include AMLS RMS training should the mission manifest require orbiter support.

When the AMLS orbiter is docked with the SSF, the commander of the SSF will control the flight elements and the Space Station Control Center will control the ground elements. The AMLS mission manager and communications officer will be in direct interface with SSCC and AMLS crew.

5.4.3 Flight/Mission Ground Network Capability

The combined L/MCC will allow acquisition of common resources and platforms with functional requirements addressed in the support software. This commonality will reduce spares inventories and contribute toward economies of scale during the development cycle and the operational life of the systems. This approach also allows one set of common personnel to support for all operations (ground and flight). The general description and physical characteristics of the facility itself were discussed previously in Section 5.3.5.

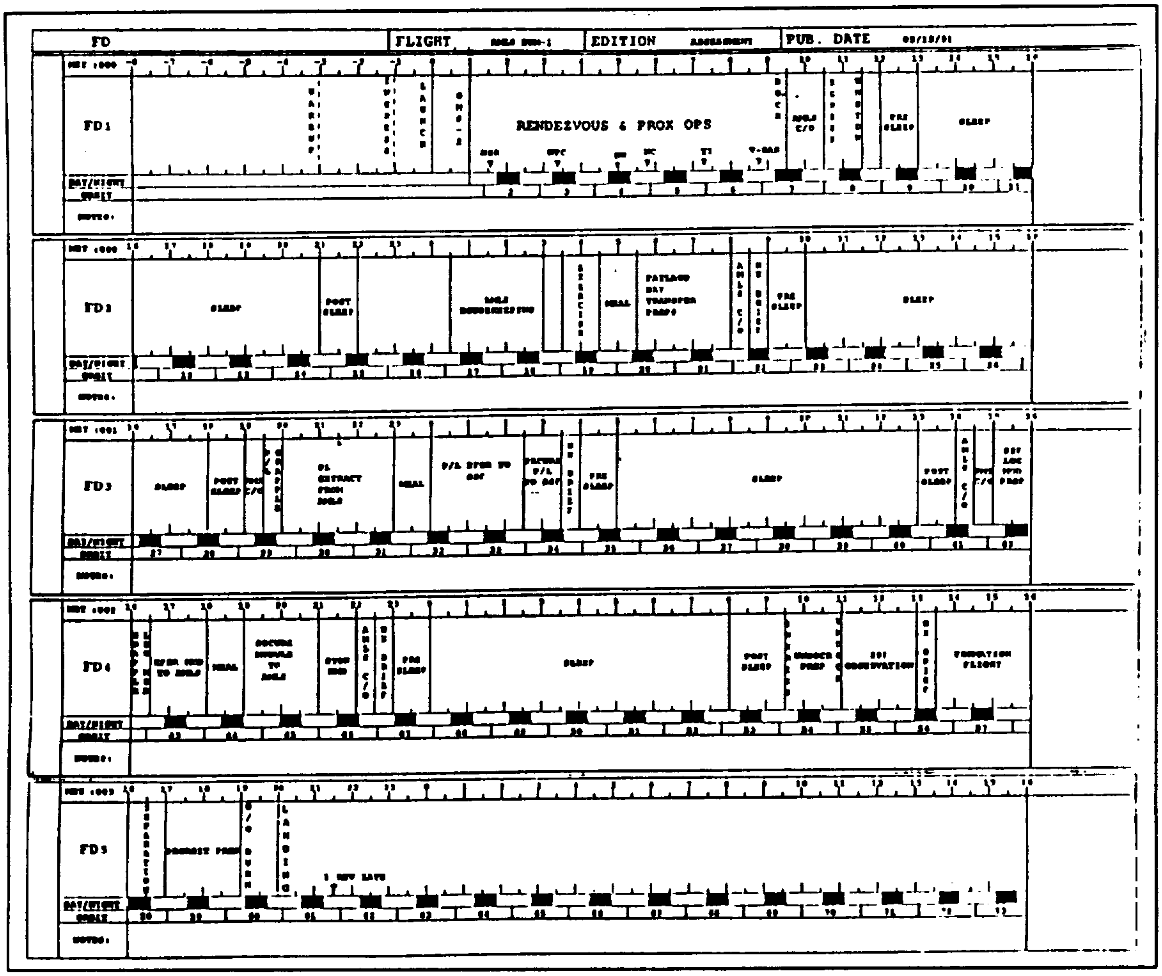


Figure 5-22. Mission Timeline.

In general, the system has been structured into functional elements consisting of the: 1) Communications and Data Distribution System, 2) Data Storage and Retrieval System, 3) Flight Design, Command, and Timeline System, 4) Operations Support System, 5) Simulation and Training Systems, 6) Ground Support System, and 7) Ground System Development.

The use of next generation software, highly structured applications, macros and "packages", and Commercial-Off-the-Shelf (COTS) software will significantly reduce the AMLS operations support software from comparable NSTS flight operations systems. The software requirements for the AMLS flight operations are shown in Table 5-13, along with first engineering development time estimates.

Table 5-13. Flight and Mission Ground Network Requirements.

FUNCTION	DEVELOPMENT TIME	SOFTWARE LINES OF CODE
Operations Support	42 Months	750K
Data Storage & Retrieval	Acquisition Time	Commercial Off-the-shelf
Flight Design, Analysis, Command, & Timeline	48 Months	1.82M
Communications and Data Distribution	18 Months	200K
Ground Support	36 Months	500K +Comm'l Off-the-shelf
Ground System Development	36 Months	1M + Comm'l Off-the-shelf
Simulation & Training	42 Months	1M + Comm'l Off-the-shelf

5.4.4 Manpower Requirements

The AMLS flight operations organization is detailed in Table 5-14. The organization is structured along functional lines with team support. Each function (i.e., flight design, training, etc.) works on multiple missions in the flight operations preparations queue. After OFT flights are complete, the flight operations preparation process should be stable and repetitive, thus reducing the time and manpower required. Flight design and planning functions and crew activity planning will address minor variations in the DRM-1 missions due to payload manifest and varying logistics supply/return weights and support requirements. Phasing orbit(s) for rendezvous will have variations due to orbiter/SSF initial relationships. Because AMLS flight will be standardized, only minor updates to the flight and ground support documentation will be necessary if the payload manifest, logistics requirements, or SSF rendezvous phasing orbits vary significantly from the standard. The standardized training scenario will also be updated, if required, to accommodate significant variations. The same staffing that supports the OFT flights will transition to support the DRM-1 missions.

The organization will be divided into two teams, with each team working on two missions at a time. Based on a ten flight per year mission model, equal periodic spacing between flights, and approximately 20 weeks of preparation per mission, normally four missions will be in various stages of preparation. It is expected that flight operations preparation activities will take place on a 5 day, 1 shift work schedule.

The individual functions shown in Table 5-14 include the required compliment of technician support. The integrated operations concept makes it feasible to assume the technician support could "float" between launch and flight organizations as workload and scheduling requirements dictate, providing a degree of job diversity.

Table 5-14. Flight Operations Support Manpower Requirements.

OFFICE	PERSONNEL	INCLUDED TECHNICIANS
Flight Operations Director	3	-
Flight Crews	12	-
Common Support	Table 5-8	Table 5-8
Flight Design & Planning	22	5
Crew Activity Planning	12	3
Flight Products & Documentation	17	-
Flight Operations Training	41	9
Flight Operations Support	49	20
Total	*156	*37

* Not including common support

The teams preparing the OFT mission (Figure 5-19) will transition to support operational flights. A total of 608 manweeks are required to support each of the ten operational flights per year (Figure 5-23), while 1686 manweeks are required for each of the two OFT flights per year (Figure 5-24). During the OFT phase flight operations, an additional 50-60% (_840-1010 hrs per mission) will be required for personnel skills development, production training, certification, system verification, etc. (608 manweeks * 10 flight/year / 52 weeks = _117 men while 1686 manweeks * 2 flights/year / 52 weeks + 50-60% = _ 103 men [+12% vacation, etc = 115 men]). The number of personnel required for each function is shown in Figure 5-25.

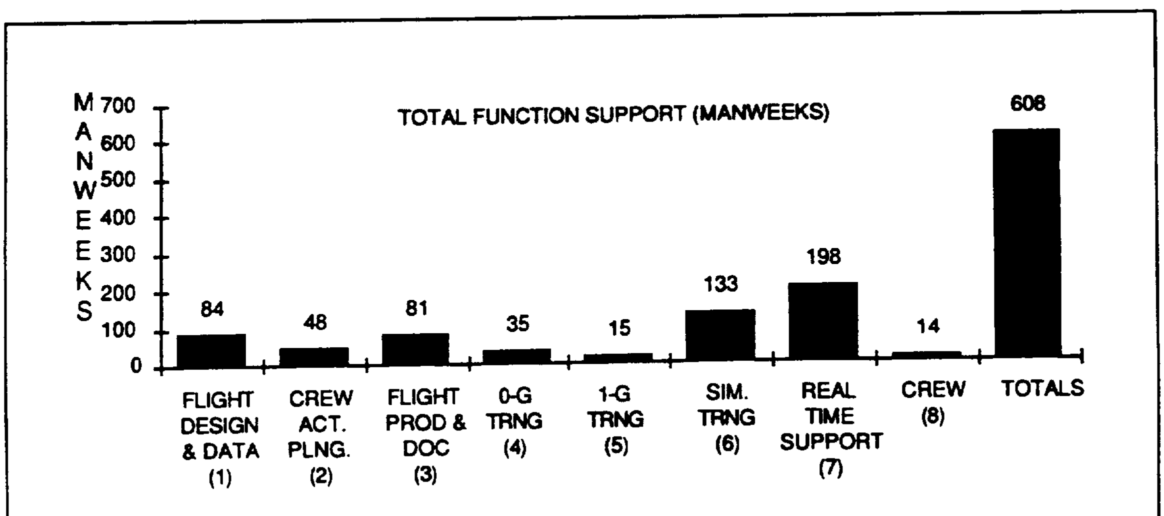


Figure 5-23. DRM-1 Production by Function.

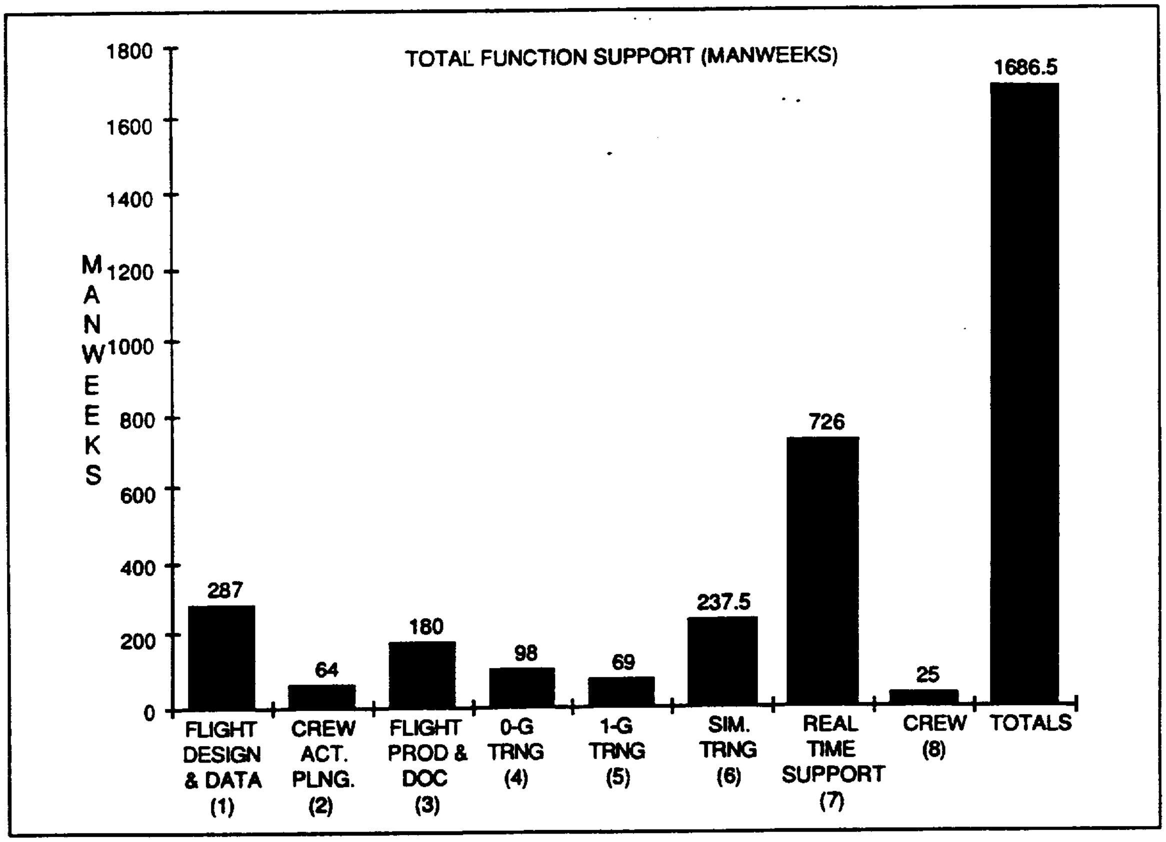


Figure 5-24. OFT production by Function.

The flight operations director will be accountable to the AMLS Operations Center Director for all flight operations functions. The common support functions (Human Resources; Finance/Account; Site Directors Office; Legal Contracts; Production, Planning, and Control; Engineering; Quality/Safety; Support; and Logistics) are defined in Appendix D for ground operations support will also support the flight operations functions. These common support functions would also be accountable to the AMLS Operations Center Director and would provide matrix support to the flight operations and launch operations organizations.

Two flight operations real time support teams under the control of the AMLS Mission Manger consists of:

<u>BOOSTER</u>

- Propulsion Officer
- GN&C Officer
- Data Processing System Officer

<u>ORBITER</u>

- Propulsion Officer
- GN&C Officer
- Data Processign System Officer
- Systems Engineer, Communications Officer
- Flight Dynamics Officer

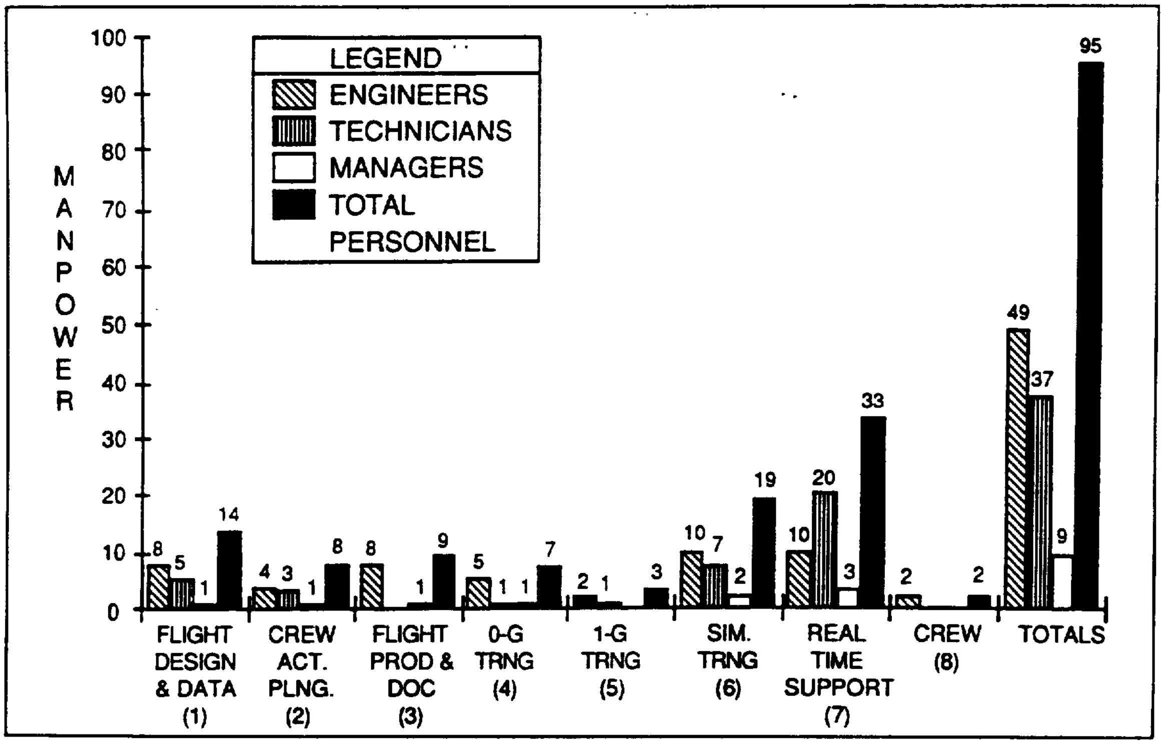


Figure 5-25. OFT and Mature Operations Mission Production Staff.

Operations control center support is expected to require a full compliment of console support during ascent, rendezvous and entry. During docked operations, the mission manager and communications officer will be on duty to provide on-orbit support with other disciplines on-call.

5.4.5 Facility Requirements

The facility requirements for flight support of the AMLS are shown in Table 5-15. As indicated, the training function requires a new 0-G training facility (Water tank), 1-G training facility, and simulator facility, as well as office space for 41 personnel. The planning function (Flight Design and Planning, Crew Activity Planning [CAP], and Flight Products and Documentation) requires office space (with PC workstations) for 40 personnel, with a text and graphics publication system needed to support the Flight Products and Documentation activity. Real time mission support functions requires office space for 49 personnel with PC workstation support. In addition, office space for the 12 AMLS crew members is required. Except for the training facilities and the operations control center, the nature of the facilities are classic office and workstation environments. It will be possible to maintain flight design and crew timeline real time support from the workstation areas with the addition of audio communication nodes within the respective office areas.

Table 5-15. Flight Operations Facility Requirements.

FUNCTION	FACILITY REQUIREMENTS	RATIONALE
Flight Design & Planning	16 Office Spaces w/Workstations	Flight Design Team
Crew Activity Planning	8 Office Spaces w/Workstations	Crew Activity Planning Team
Flight Products & Documentation	16 Office Spaces w/Workstations Text/Graphics Publication System	Flight Procedures & Flight Data File Support
Training	41 Office Spaces w/PC Support 0-g Training Facility (Water tank) 10,000 sqft Simulator Facility 5,000 sqft 1-g Training Facility	Instructors for Simulator, 1-g & 0-g Trainers Training System Facilities
Mission Support	49 Office Spaces w/PC Support Baseline Ops Control Centers Computer Systems Center	Flight Control Support Support training
Crew	12 Office Spaces w/PC Support	Crew requirement

5.5 SUPPORTABILITY

The primary role for the logistics analysis activity has been to provide the recommended program spares quantities, off-equipment training/certification requirements, repair estimates, depot support personnel requirements, and predicted repair quantities based on the Rockwell spares and repair models.

Logistics has been an active member of the concurrent engineering team during the conceptual design analyses activity. Contributions have been made to: 1) influence design by development of requirements and examination of subsystem configurations, 2) identification of logistics drivers, and 3) defining off-vehicle ground operations/processing through support system assessment using various analytical approaches.

5.5.1 Logistics Support Concept

Our support concept is directly traceable to the program goals of reduced operations costs and ground operations simplicity. Logistics support requirements are developed and imposed on the system design early to facilitate achievement of the program objectives.

A planned design and support infrastructure implies that: 1) a maintenance and operations program will require minimal activity on the vehicle, 2) automation of current processes reduces maintenance time and the associated administrative activities, and 3) it takes advantage of multipurpose ground support and test equipment to reduce the range and depth of required support.

A reduced initial support investment implies that : 1) the system will utilize existing assets where practical, and 2) the burden of building a large depot repair capability and/or spares stock be eliminated by employing repair warranty concepts.

A reduced maintenance demand implies that: 1) every vehicle system will not be re-certified prior to each flight, and 2) proven hardware with known reliability performance will be used to reduce maintenance requirements.

No launch delays for normal maintenance implies that: 1) establishment of repair time requirements, regardless of repair location will decrease risks associated with launch schedules/windows, and 2) vehicle systems and subsystems will be designed to ensure achievement of repair time requirements.

The logistics support concept was determined by first examining the factors that drive logistics. Off-line maintenance drives the logistics support requirement from a maintenance aspect. Three types are resources are required: 1) Spare vehicle LRUs and or maintenance consumables, 2) support equipment, and 3) depot technicians (separate from those identified for ground/flight processing). There is also a fourth but intangible resource consumed and that is time. In determining support resources (warehousing, support equipment spares, test equipment for support equipment, personnel training, and operations/maintenance instruction) time must be evaluated for turnaround of repair resources. Spares, support equipment, and manuals are significant drivers of life cycle costs.

The logistics program costs for the following items were evaluated:

- Depot Support Equipment
- Organization Maintenance
- Depot Maintenance
- Packaging, Handling, Storage, and Transportation
- Depot Manuals
- Organizational Training
- Depot Training
- Consumables
- Warehousing
- ILS Management

The assessment included the following factors:

- Vehicle Description - Crew size, weights
- Operations Description - Number of vehicles, operating hours/years, power on times
- R/M Factors - reliability, MTBR, MTBM, MH/MA, sufficiency levels
- Depot Factors - turnaround times, mean time to repair
- Logistics Factors - transportation, LRU types, manuals

5.5.2 Supportability Study Results

The tabulated results obtained from the Front-End Analysis of System Equipment Requirements (FASER) model are shown in Table 5-16. The model used the following types of data to determine the rate, safety, and condemnation spares:

- Ground Power On Time
- Flights Per Year
- Flight Power On Time
- Total Expected Flights
- Mean Time Between Removals Factor
- Number of Vehicles
- Average Removal Turnaround Time
- Probability of Sufficiency
- Removal Turn Around Time Factor

Rate spares ensure that there are spare assets in the system. When an item enters the repair cycle, another is available "on the shelf" for immediate installation on the vehicle. The FASER model employed the Poisson process (similar to that used to determine NSTS orbiter spares) to determine AMLS vehicle spares.

Repeated removal and repair of a component may fatigue and wear out the component. The aggregation of component fatigue eventually leads to a condition where repair is not economical relative to the component's unit cost. At that time, the component is "condemned" or discarded. The FASER model condemnation rates are the same as those used on the Shuttle program (2% - 3%).

When the FASER model analysis did not indicate a need for a rate or condemnation spare because the item's failure rates are so low, a safety spare is recommended. Otherwise, if no spares were on hand and a failure occurred, there would be no replacement items to install while the failed unit was in the repair cycle.

Table 5-16. FASER Model Spares Results.

SPARES	BOOSTER	ORBITER	TOTAL
Rate	8	39	47
Condemnation	28	73	101
Safety	53	55	108

The FASER model was used to perform sensitivity analyses by varying: 1) Repair Turnaround Time, Flight Power On Time, Ground Power On Time, Probability of Sufficiency, and Annual Flight Rate (See Table 5-17). The results of the analysis showed for the booster, varying the Ground Power On Time produced the largest effect (Figure 5-26). No noticeable effect was shown when the Flight Power On Time was varied due to the extremely short booster flight duration. Varying both the Flight and

Ground Power On Time produced the largest increase in spares required for the orbiter (Figures 5-27 and 5-28). The number of spares required for the booster or orbiter varied negligibly when the Repair Turnaround Time, Probability of Sufficiency, Number of Vehicles, or Annual Flight Rate was varied due to the vehicle's high reliability.

Table 5-17. FASER Model Sensitivity Analyses Values.

SENSITIVITY VARIABLE	BASELINE INPUTS		VARIANCES	
	ORBITER	BOOSTER	ORBITER	BOOSTER
Repair Turnaround Time	90 days	90 days	30 - 180 days	30 - 180 days
Flight Power on Time	90 hours	0.25 hours	90 - 168 hours	0.167 - 0.25 hours
Ground Power on Time *	24 hours	38 hours	24 - 500 hours	38 - 500 hours
Probability of Sufficiency	0.95	0.95	0.85 - 0.975	0.85 - 0.975
Number of Vehicles	5 each	5 each	4, 5, 6	4, 5, 6
Annual Flight Rate	10/year	10/year	5 - 15/year	5 - 15/year

* Note: Ground Power On Times are ROM estimates. The booster estimate is higher than that for the orbiter based on additional testing for the higher capability avionics systems (booster requires remote piloting capability)

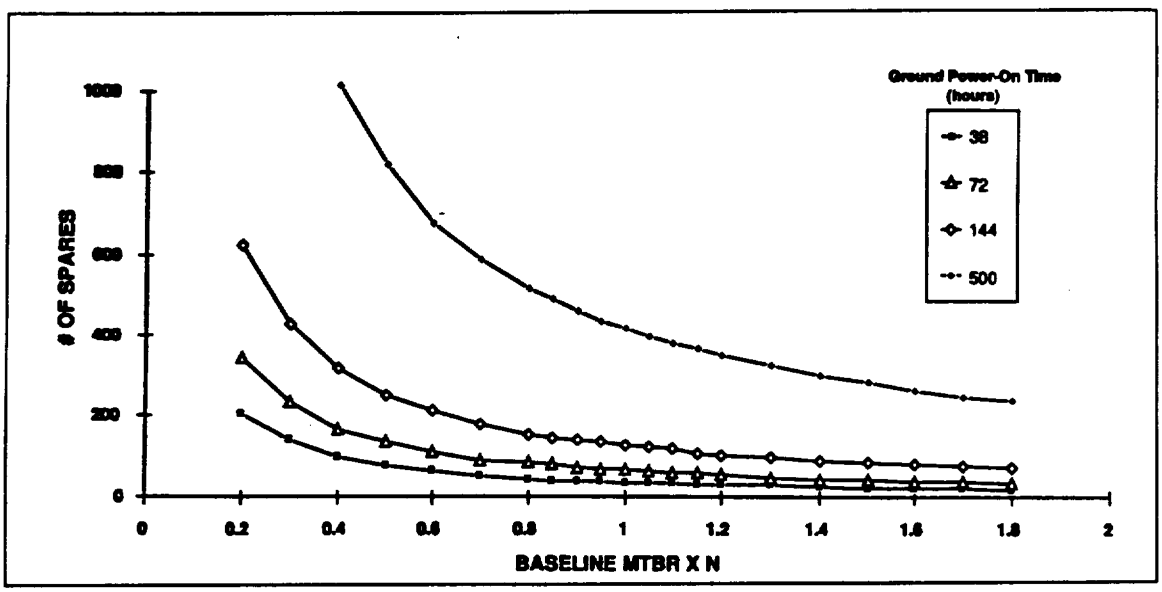


Figure 5-26. Booster Ground Power On Time Sensitivity.

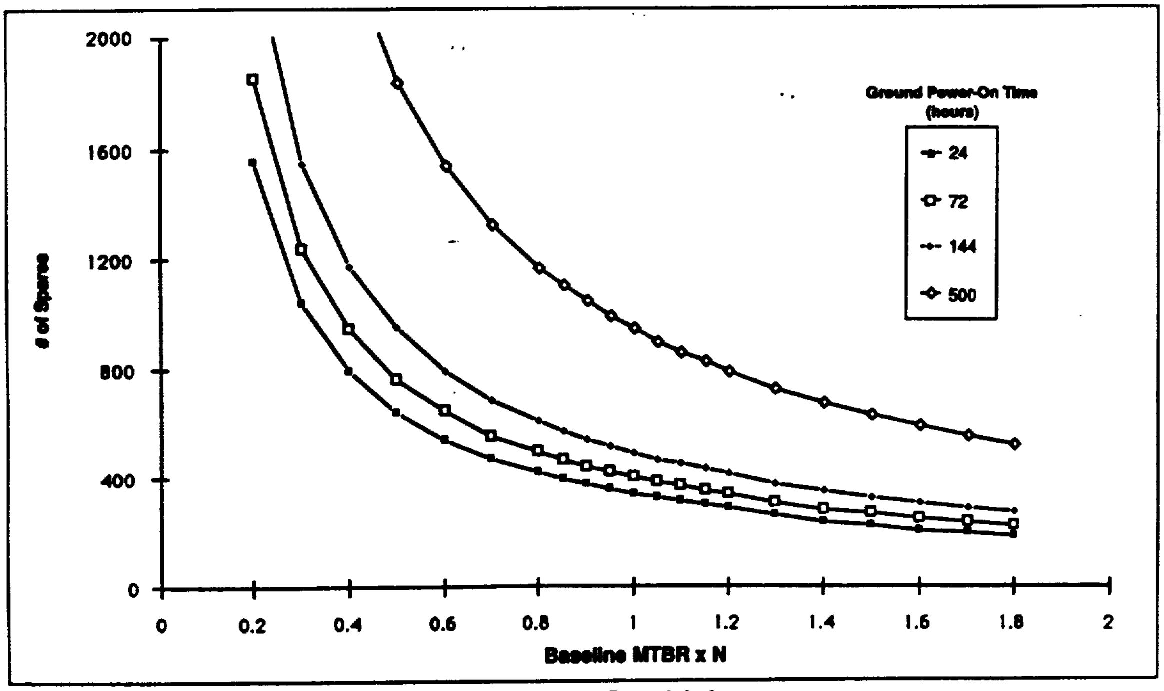


Figure 5-27. Orbiter Ground Power On Time Sensitivity.

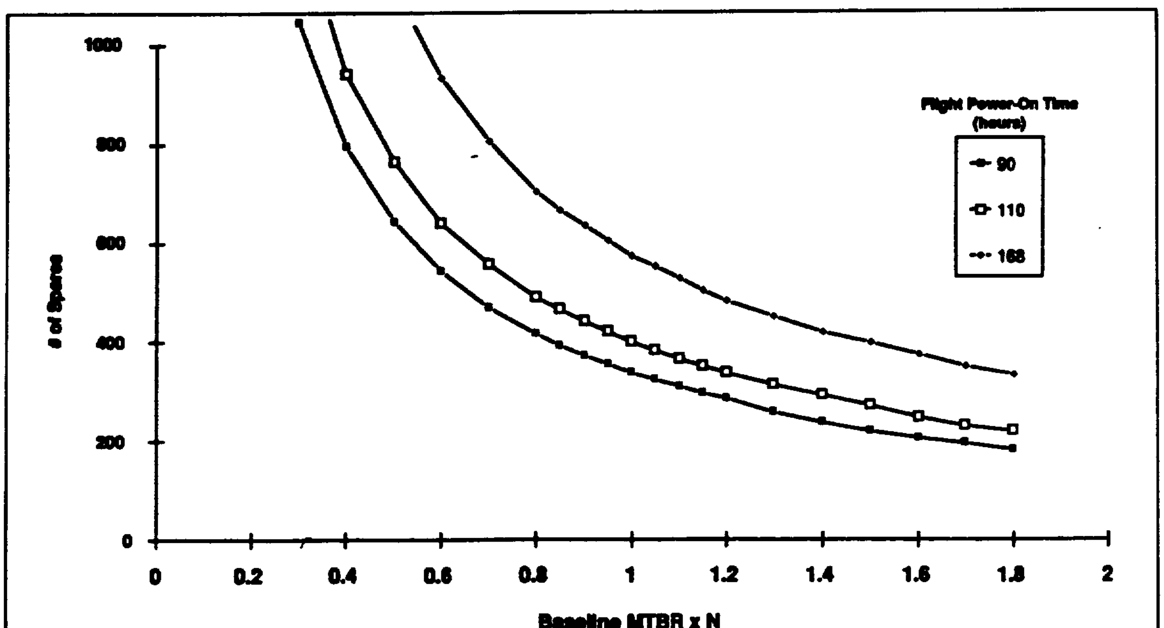


Figure 5-28. Orbiter Flight Power On Sensitivity.

6.0 LIFE CYCLE COST ANALYSIS

This section documents the database development for the Life Cycle Cost Analysis. These data have been developed based upon accomplishing the specific major activities related to design, development, production, test, verification, safety, reliability, quality assurance, and management and control for both hardware and software. Life cycle cost data have been extracted from these efforts and are reported or excerpted here. When this would result in duplicating a very large multi-page table, an excerpt is provided here as well as a reference to the full table. These data are also being provided in electronic spreadsheet form.

The AMLS Life Cycle Cost Analysis Task collected the information developed in the other Tasks relevant to estimating Life Cycle Costs and prepared that information for use in cost models. For the AMLS Study, the actual Life Cycle Cost estimates are being made by Langley Research Center and this report documents the physical and programmatic characteristics of the AMLS in a consistent form to facilitate cost estimating and projections of cost variance.

The AMLS program is founded upon developing innovative and effective ways of assuring realistic life cycle costs for future space transportation systems. These innovative ways include implementing and merging operations and support, planning and requirements, and manufacturing producibility into a design that will provide a safe, reliable and affordable vehicle. To do this, a solid knowledge base is referenced that can avoid issues which have occurred before and build on their solutions to benefit the AMLS system. Our experience base permits us to establish several key elements that will facilitate the Design, Acquisition and Operations Phases:

- Accomplish operation planning and support (logistics) early in the program definition phase.
- Develop design solutions that minimize adverse operational impacts.
- Involve manufacturing planning early to minimize parts counts and provide simple designs and processes.
- Allow for adequate development hardware for verification and off-nominal testing.
- Fund and complete technology developments early.
- Assess software requirements early and define a plan for their implementation.
- Provide for performance reserve (design margin) in the system.
- Keep interfaces simple.
- Base system definitions on total life cycle cost.
- Base design requirements on a realistic mission model.

The physical and programmatic information database has been developed with consideration for this experience.

The Life Cycle Cost (LCC) Database task for this task assignment of the AMLS study is different from the initial task for the Personnel Launch System in that Rockwell is not estimating the costs directly. The actual cost estimates will be made by the Langley Research Center using data collected and organized by Rockwell.

The physical and programmatic information used to determine costs covers many aspects of the AMLS program: Hardware, Software, Facilities, and Supporting Equipment as well as the staff to operate them safely and effectively over the 30 year operational life of the program. This information is organized by a 3-Axis Work Breakdown Structure illustrated in Figure 6-1. The WBS has been adapted from the WBS originally formulated for the earlier Personnel Launch System (PLS) Study, Reference 6-1.

The hardware development and production costs for the AMLS will be estimated using the GE PRICE parametric cost estimating program. Some of the input variables from this program, such as weight, are readily determined; others are subjective and/or require information which is not usually documented at this early phase of program evolution. This database task has collected both. Most of these data are reproduced in this report as well as being supplied in electronic form.

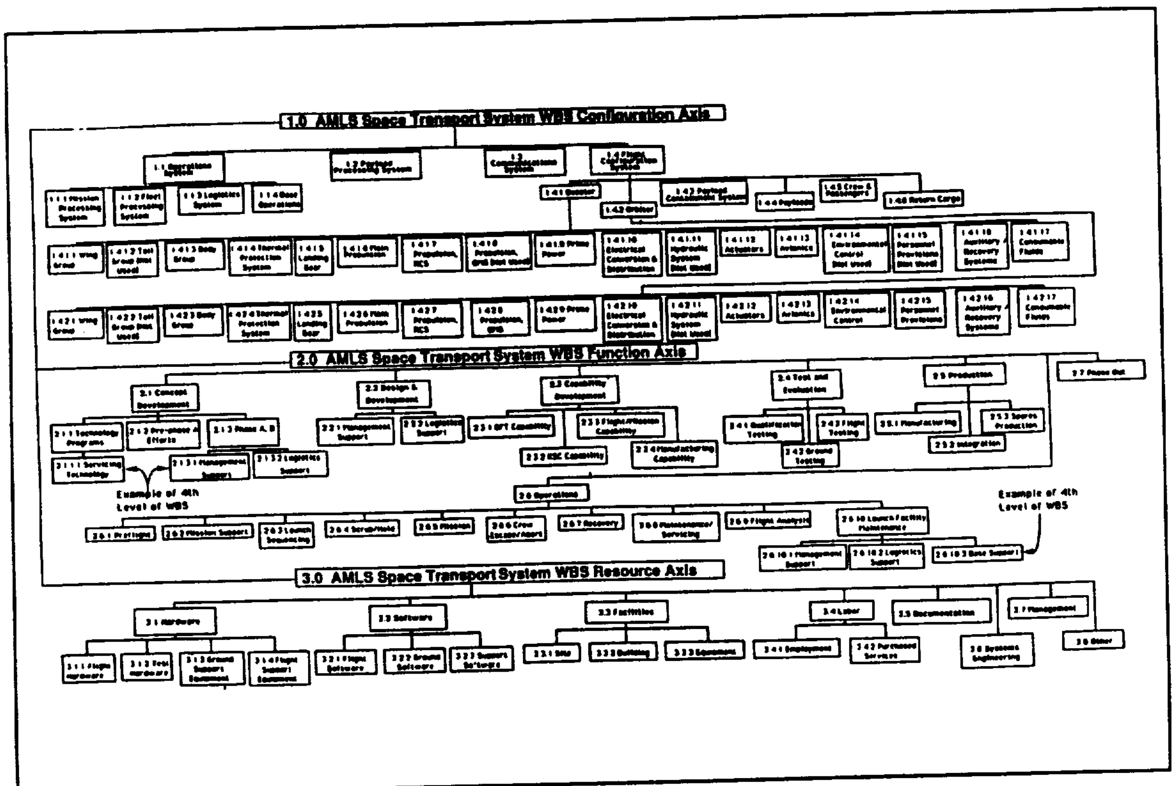


Figure 6-1. 3-Axis Work Breakdown Structure.

Other portions of the AMLS program will be estimated with different methods and models. Tables of the information known to determine these costs are being provided in the areas of Personnel, Logistics, Facilities, Equipment, and Software. Technology availability has been assessed and development program plans, schedules, and funding requirement estimates for the critical technologies have been developed and presented in the AMLS Technology Development Plan (DRD 8), Reference 6-2. Initial estimates for many of the AMLS characteristics have been incorporated into electronic tables (spreadsheets).

6.1 FLIGHT VEHICLES

An excerpt of the Booster Work Breakdown Structure and the information collected is presented in Table 6-1. These estimates cover the subsystem weights, materials, fabrication and assembly methods, and technology concerns. The same information has also been collected for the Orbiter.

Subsystem weight is known to be a principal predictor of cost. Weight and weight growth were estimated and allocated based on our experience with the Shuttle and other space systems. Experience indicates that there are two potential sources of errors in weight estimates: (1) a tendency for early studies to underestimate actual final weights, and (2) a random error or variation about the final weight. To produce these estimates, the percentage weight growth for Shuttle subsystems was examined for applicability to the AMLS subsystems. Growth and variation percentages were chosen based on a combination of Shuttle experience and engineering judgement. These percentage estimates were applied to allocate the overall dry weight growth margin of about 15 percent projected for the AMLS based on the Shuttle experience.

Additional information was collected to permit calculation of complexity factors for use in estimating costs with the G.E. PRICE cost estimating program. Cost estimates developed with the G.E. PRICE model use weight and manufacturing complexity as major cost determinants. The G.E. PRICE manufacturing complexity factors also depend upon the type of material and fabrication accuracy required.

The accuracy required for the weight estimates of the different materials comprising each subsystem is approximately the same as required for the Shuttle Orbiter. For most structural elements, a fabrication accuracy of $\pm$ 0.03 inches suffices and is relatively easy to achieve. Where higher accuracy is required, a variety of techniques are available to achieve the accuracy and/or precision needed in local areas without imposing a higher standard on the entire component. Other data elements provide estimates of design difficulty and integration difficulty.

Table 6-1. Booster WBS Elements.

AMLS BOOSTER WBS INFORMATION MATRIX		ENGINEERING DESIGN			WEIGHTS		
WBS #	ELEMENT	WEIGHT	GROW%	Var %	LOW Cost	NOMINAL Cost	HIGH COST
1.4.1	BOOSTER						
1.4.1.1	WING GROUP	9,132	18.00%	5.00%	10,324	10,780	11,237
1.4.1.1.1	WINGS (QNA=2)	9,132	18.00%	5.00%	10,324	10,780	11,237
1.4.1.1.1.1	WING BODY						
1.4.1.1.1.2	LEADING EDGE		18.00%	5.00%			

--QUANTITIES--					MATERIAL	MANUFACTURING FAB METHOD/ASSEMBLY METHOD
FLEET	TEST	LOGISTIC	VOLUME	POWER		
5						
5	2.5	1			Graphite Polyimide	- THE WINGS ARE FABRICATED OF G/PI - BOX BEAM WITH SPARS AND STRINGERS. THE SKINS ARE MECHANICALLY FASTENED TO THE INTERNAL STRUCTURE. THE SPARS ARE SOLID LAMINATES WITH STIFFENERS; THEY ARE LAYED UP AND HEATED IN AN AUTOCLAVE. THE RIBS ARE OPEN TRUSS PLATES MADE OF GRAPHITE POLYIMIDE LAMINATES. THE FORWARD SPAR IS ATTACHED TO THE LH2 TANK WALL BY VERTICAL LINKS. THERE ARE TWO MAIN SPARS, WHICH CARRY THE LOADS TO THE RIGID ATTACHMENT AT THE AFT STRUCTURE.
5	3	1			Titanium	- THE LEADING EDGE IS FABRICATED OF TITANIUM IN SECTIONS AND IS MECHANICALLY FASTENED

MANUFACTURING FACILITY	DEVELOPMENT TESTS: TEST ARTICLES	QTY	STA	DYN	PROOF	V-A	THERM	PERFORM
RI - TULSA	BUILT UP SEGMENT		√					
RI - TULSA	BUILT UP SEGMENT						√	

DEVELOPMENT TEST FACILITIES/EQUIPMENT	QUALIFICATION TESTS: TEST ARTICLES	QTY	STA	DYN	PROOF	V-A	THERM	PERFORM
	STATIC TEST ARTICLES	2.5	√			√	√	√
SUPPLIER/STANDS								
DOWNEY/THERMAL								

QUALIFICATION TEST FACILITIES/EQUIPMENT	MAJOR TEST ARTICLES- COMPONENTS/FACILITIES/EQUIPMENT: STA	MPTA	ALT	OFT	ADL	SAIL	FACILITIES/EQUIPMENT
PALMDALE/STATIC TEST STAND	√		√	√			

6.2 PERSONNEL

A major cost in aerospace operations is people. Estimates of the headcounts for AMLS Operations Phase Personnel are presented in Table 6-2. They are grouped into three major areas: Operations, Logistics, and Sustaining Engineering.

Table 6-2a. AMLS Operations Personnel.

	Low Estimate							Nominal Estimate							High Estimate						
	Manpower Headcount							Manpower Headcount							Manpower Headcount						
2.0 AMLS WBS Function Axis	Astron	Mgmt	Engrs	Techns	Support High	Support Low	Total	Astron	Mgmt	Engrs	Techns	Support High	Support Low	Total	Astron	Mgmt	Engrs	Techns	Support High	Support Low	Total
Total Identified Operations Positions - 100	12	172	752	890	75	220	2121	12	212	1175	1082	97	248	2830	18	348	1733	1474	181	434	4188
2.1 Concept Development																					
2.1.1 Technology Programs																					
2.1.1.1 Servicing Technology																					
2.1.2 Pre-phase A																					
2.1.3 Phase A, B																					
2.1.3.1 Management Support																					
2.1.3.2 Logistics Support																					
2.2 Design & Development																					
2.2.1 Management Support																					
2.2.2 Logistics Support																					
2.2.3 Sustaining Engineering		(27)	(330)	(65)	(15)	(55)	(500)		(55)	(700)	(170)	(25)	(50)	(1000)		(110)	(1000)	(180)	(60)	(150)	(1500)
2.2.3.1 SE -Booster		(27)							(55)							(110)					
2.2.3.2 SE-Orbiter		5	65	15	3	10	100		10	135	40	5	10	200		20	200	40	10	30	300
2.2.3.3 SE-Propulsion		5	65	15	3	10	100		10	135	40	5	10	200		20	200	40	10	30	300
2.2.3.4 SE-Crew/Cabin/Cargo Sys		5	65	15	3	10	100		10	135	40	5	10	200		20	200	40	10	30	300
2.2.3.5 SE Systems Integration		5	65	15	3	10	100		10	135	40	5	10	200		20	200	40	10	30	300
2.3 Capability Development		7	70	5	3	15	100		15	160	10	5	10	200		30	200	20	20	30	300
2.3.1 OFT Capability																					
2.3.1.1 Management Support																					
2.3.1.2 Logistics Support																					
2.3.2 KSC Capability																					
2.3.2.1 Management Support																					
2.3.2.2 Logistics Support																					
2.3.3 Flight/Mission Capability																					
2.3.3.1 Management Support																					
2.3.3.2 Logistics Support																					
2.3.4 Manufacturing Capability																					
2.3.4.1 Management Support																					
2.3.4.2 Logistics Support																					
2.4 Test and Evaluation																					
2.4.1 Qualification Testing																					
2.4.1.1 Management Support																					
2.4.1.2 Logistics Support																					
2.4.2 Ground Testing																					
2.4.2.1 Management Support																					
2.4.2.2 Logistics Support																					
2.4.3 Flight Testing																					
2.4.3.1 Management Support																					
2.4.3.2 Logistics Support																					
2.5 Production																					
2.5.1 Manufacturing																					
2.5.1.1 Management Support																					
2.5.1.2 Logistics Support																					
2.5.2 Integration																					
2.5.2.1 Management Support																					
2.5.2.1 Logistics Support																					
2.5.3 Spares Production																					
2.5.3.1 Management Support																					
2.5.3.2 Logistics Support																					
2.5.4 Logistics Program		(78)	(187)	(454)	(14)	(67)	(800)		(87)	(211)	(507)	(17)	(72)	(894)		(134)	(330)	(720)	(26)	(111)	(1321)
2.5.4.1 Management Support		(78)							(87)							(134)					
2.5.4.2 Depot Support Eqpt		7	17	45	0	4	(73)		7	20	50	0	4	(81)		12	30	75	0	6	(123)
2.5.4.3 Depot Maintenance		4	9	27	0	3	(43)		5	10	30	0	3	(48)		10	15	45	0	5	(75)
2.5.4.4 Depot Manuals		3	21	6	2	6	(38)		4	25	5	2	5	(41)		8	37	6	3	10	(64)
2.5.4.5 Depot Training		55	135	335	8	29	(563)		60	150	370	10	20	(610)		90	260	525	15	30	(920)
2.5.4.6 Consumables		0	5	40	2	16	(63)		7	5	50	2	10	(74)		10	7	70	3	15	(105)
2.5.4.7 Warehousing		3	0	2	2	25	(32)		4	1	2	3	30	(40)		4	0	3	4	45	(56)
2.6 Operations	12	67	227	371	46	98	821	12	71	264	410	55	118	930	18	104	394	566	76	172	1331
2.6.1 Prelaunch		(5)	(47)	(10)			(62)		(5)	(53)	(12)			(70)		(7)	(77)	(21)			(105)
2.6.1.1 Management Support																					
2.6.1.2 Logistics Support																					
2.6.1.3 Res Crew Activity Planning		1	7	2			10		1	8	3			12		1	12	5			18
2.6.1.4 Training O-G		1	4	1			6		1	5	1			7		1	7	2			10
2.6.1.5 Training1-G		0	4	1			5		0	4	1			5		0	5	2			7
2.6.1.6 Simulator		2	18	0			20		2	20	7			29		3	30	12			45
2.6.1.7 Flt Prod, Doc, & Post Flt Anal		1	14				15		1	16				17		2	23				25
2.6.2 Mission Support		(1)	(12)	(4)			(17)		(1)	(16)	(5)			(22)		(1)	(25)	(8)			(34)
2.6.2.1 Management Support																					

Table 6-2b. AMLS Operations Personnel. (Continued).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1				Low Estimate							Nominal Estimate							High Estimate				
2		-------------Manpower			Headcount------------				-------------Manpower			Headcount------------				-------------Manpower			Headcount------------			
3						Support	Support						Support	Support						Support	Support	
4	2.0 AMLS WBS Function Ado	Astna	Mnrs	Engrs	Techns	High	Low	Total	Astna	Mnrs	Engrs	Techns	High	Low	Total	Astna	Mnrs	Engrs	Techns	High	Low	Total
74	- 2.0.2.2 Logistics Support																					
75	- 2.0.2.3 Flight Ops		(1)	(12)	(4)			(17)		(1)	(16)	(5)			(22)		(1)	(25)	(8)			(34)
76	- 2.0.2.3.1 Flight Design & Planning		1	12	4			17		1	16	5			22		1	25	8			34
77	- 2.0.3 Launch Sequencing(50% of effort)			(27)	(10)			(45)			(20)	(20)			(40)			(35)	(30)			(65)
78	- 2.0.3.1 Management Support																					
79	- 2.0.3.2 Logistics Support																					
80	- 2.0.3.3 Mission Manager			4				4			6				6			6				6
81	- 2.0.3.4 Orb Systems Engineer			2				2			2				2			3				3
82	- 2.0.3.5 Orb Comm. Officer			2				2			2				2			3				3
83	- 2.0.3.6 Orb Flt Dynamics Officer			2				2			2				2			3				3
84	- 2.0.3.7 Orb Propulsion			2				2			2				2			3				3
85	- 2.0.3.8 Orb GN&C			2				2			2				2			3				3
86	- 2.0.3.9 Orb DPS			2				2			2				2			3				3
87	- 2.0.3.10 Sep Propulsion			2				2			2				2			3				3
88	- 2.0.3.11 Sep GN&C			2				2			2				2			3				3
89	- 2.0.3.12 Sep DPS			2				2			2				2			3				3
90	- 2.0.3.13 Backup			6	16			22			6	20			28			6	30			30
91	- 2.0.4 Scrub/Hold																					
92	- 2.0.4.1 Management Support																					
93	- 2.0.4.2 Logistics Support																					
94	- 2.0.5 Mission (50% of 2.0.3)	(12)	(1)	(8)	(3)	(1)	(1)	(17)	(12)	(1)	(8)	(2)	(2)	(2)	(19)	(10)	(2)	(8)	(4)	(3)	(3)	(28)
95	- 2.0.5.1 Management Support		1			1	1	3		1			2	2	5		2			3	3	8
96	- 2.0.5.2 Logistics Support							0							0				1			1
97	- 2.0.5.3 Flight Crew	12						12	12						12	10						10
98	- 2.0.5.4 Flight Support				3			2				2			2				3			3
99	- 2.0.6 Crew Escape/Abort																					
100	- 2.0.6.1 Management Support																					
101	- 2.0.6.2 Logistics Support																					
102	- 2.0.7 Recovery																					
103	- 2.0.7.1 Management Support																					
104	- 2.0.7.2 Logistics Support																					
105	- 2.0.8 Turnaround		(69)	(141)	(337)	(46)	(97)	(690)		(64)	(166)	(377)	(53)	(110)	(770)		(94)	(257)	(505)	(73)	(179)	(1108)
106	- 2.0.8.1 Management Support		(5)	(0)	(0)	(0)	(19)	(24)		(5)	(0)	(0)	(11)	(11)	(27)		(5)	(0)	(0)	(14)	(12)	(31)
107	- 2.0.8.1.1 Managing Directors Office		2			1		3		2			1		3		2			1	1	4
108	- 2.0.8.1.2 Finance/Accounting		1	0	0	4	6	11		1	0	0	5	6	12		1	0	0	6	6	13
109	- 2.0.8.1.3 Human Resources		1			3	3	7		1			4	3	8		1			5	3	9
110	- 2.0.8.1.4 Legal/Contracts		1			1	2	4		1			1	2	4		1			2	2	6
111	- 2.0.8.2 Logistics Support		1	6	10	5	6	28		1	6	10	5	6	28		1	10	15	6	6	38
112	- 2.0.8.3 Ground Operations		(10)	(60)	(111)	(25)	(30)	(250)		(10)	(66)	(126)	(31)	(43)	(282)		(28)	(100)	(186)	(43)	(71)	(430)
113	- 2.0.8.3.1 Site Directors Office		2			1		3		2			1		3		3			1	1	5
114	- 2.0.8.3.2 Production Planning & Control		3	6	5	9	8	30		2	5	6	9	6	29		3	10	8	0	16	39
115	- 2.0.8.3.3 Engineering		2	20		6	5	33		2	30		6	5	37		3	45		0	10	58
116	- 2.0.8.3.4 Quality and Safety		3	15	25	9	10	60		3	17	26	9	10	65		5	25	40	9	15	95
117	- 2.0.8.3.5 Support		6			16	15	36		5			21	20	46		0			30	30	60
118	- 2.0.8.3.6 Processing Operations		2	9	35	4		51		3	10	42	4		59		3	15	65	5		88
119	- 2.0.8.3.7 Major Inspection Operations		2	3	0	5		10		2	3	0	5		10		3	6	0	7		16
120	- 2.0.8.3.8 Shops				46			46				62			62				75			75
121	- 2.0.8.4 On-Site Logistics		(18)	(41)	(103)	(3)	(35)	(200)		(20)	(40)	(117)	(3)	(45)	(224)		(30)	(74)	(117)	(3)	(67)	(291)
122	- 2.0.8.4.1 Logistics Management		(18)					(18)		(20)					(20)		(30)					(30)
123	- 2.0.8.4.2 Organizational Maint		6	18	37		6	66		7	20	45		6	78		10	30	45		10	95
124	- 2.0.8.4.3 Organic. Training		2	6	6			14		2	7	7			16		3	10	7			20
125	- 2.0.8.4.4 Consumables		7	18	66		6	97		8	20	70		10	108		12	30	70		15	127
126	- 2.0.8.4.5 Warehousing		3	8		3	20	35		3	2		3	30	38		8	4		3	48	64
127	- 2.0.8.5 Co-Located Depot Activities		(19)	(37)	(113)	(3)	(6)	(180)		(20)	(47)	(125)	(3)	(12)	(207)		(30)	(73)	(186)	(5)	(15)	(309)
128	- 2.0.8.5.1 Logistics Management		(18)					(18)		(20)					(20)		(30)					(30)
129	- 2.0.8.5.2 Depot Support Equipment		4	5	25			34		4	10	30			44		6	15	45			(66)
130	- 2.0.8.5.3 Depot Maintenance		2	3	10			15		2	2	20			24		3	3	30			(36)
131	- 2.0.8.5.4 Depot Manuals		2	5	5		2	14		2	6	5		6	17		3	10	10		6	(29)
132	- 2.0.8.5.5 Depot Training		10	25	65	3	7	110		12	30	70	3	7	122		10	45	100	5	10	(170)
133	- 2.0.9 Flight Analysis																					
134	- 2.0.9.1 Management Support																					
135	- 2.0.9.2 Logistics Support																					
136	- 2.0.10 Launch Facility Maintenance																					
137	- 2.0.10.1 Management Support																					
138	- 2.0.10.2 Logistics Support																					
139	- 2.0.10.3 Base Support																					
140	3.0 Phase Out																					

6.2.1 Operations Personnel

All personnel headcount estimates reflect substantial reductions from current practice with the Shuttle system and unmanned launch vehicles. These headcount estimates are goals based on examination of AMLS requirements in view of what has been accomplished with civil and military aircraft maintenance in environments which are, in many senses, harsher than spaceflight. These goals are a challenge which places a heavy and potentially costly burden on the development process to design and manufacture a vehicle that does not need extensive turn-around effort and that can be quickly fixed when a failure occours.

The headcounts reflect steady-state operations well after the orbital flight test (OFT) program is completed. In the preparation for the OFT and initial operating capability (IOC), there will be a buildup in personnel to undertake non-recurring tasks which will last at least through the year after IOC. The Flight and Ground Operations headcounts should be expected to peak at about twice the given estimates at IOC. Most of the Logistics and Sustaining Engineering people will still be part of the manufacturing effort at the time of IOC and this headcount will be many times the estimate given for the steady state.

Variation estimates for the Operations Phase headcounts are based on estimates that most functions could be accomplished by 90 percent of the nominal headcount with no lengthening of time-lines under normal circumstances. Response time for many otherwise trivial non-scheduled events would be degraded, but adequate stocks of spare/repair parts should still permit launch schedule adherence. Accordingly, an approximate 10 percent reduction was assessed against most of the identified Operations, Logistics and Sustaining Engineering functions to determine the low estimate for Operations Phase personnel. Pending further study, the high estimate for the Operations phase personnel is based on the following reasoning:

The order of magnitude reductions in personnel projected for the AMLS depend on design and development tasks which are both well understood and technically challenging. The nation already has experience with the Shuttle where operations efficiency projections were not even addressed because of severe funding constraints on the design phase. If corrective actions for any shortfalls in capability (especially in areas affecting turn-around time) are undertaken during the design phase, the AMLS is unlikely to come out of development with a lot of operations problems in many areas. The worst that is likely to happen is that the AMLS will pass through an extended test phase while a few remaining problems are corrected. Under these assumptions, the AMLS estimates are subject to a relatively small random uncertainty rather than a gross miss- or underestimate (uncertainty of scale).

The high end of this statistical uncertainty is about 50 percent. Further investigation should be able to determine operational areas where the uncertainty is different, but these judgements cannot be made at this time. Accordingly, the 50 percent is applied to all areas.

The Flight and Ground Operations people are postulated to work at the Kennedy Space Center (KSC) which is considered to be the primary launch site. An extrapolation from an informal review of Shuttle practice indicates that about one third of the Logistics personnel will be located at the Launch Site, with a very small portion of the Sustaining Engineering personnel also being located permanently at the launch site. Many factors could change this allocation, and a substantial portion of what are now considered to be remote functions could be performed near the launch site just as well as anywhere else.

Both Flight and Ground Operations headcounts reflect the trend toward relying on software to perform many of the functions which are now performed by humans for the STS. For Flight Operations, a small crew is retained to monitor the flight in case there are unanticipated malfunctions. The health monitoring system and flight software are expected to respond to all normal activities and most abnormalities. The Flight Operations team also provides mission design, software maintenance, and training for the transportation function. Major payloads such as telescopes or communications satellites are postulated to provide their own flight operations staffing. The AMLS facility is expected to provide payload operations support only during AMLS flights.

Ground Operations headcount estimates are based on two factors:

(1) an examination of normal turn-around activities for the Shuttle in light of aircraft maintenance doctrine and experience with that doctrine.

(2) projections of subsystem reliability and maintainability (MTBF and MTTR) based on the improvement from current Shuttle experience toward current aircraft experience. The use of health monitoring sensors and software for performance trend analysis are projected to eliminate many turn-around tasks now performed on the Shuttle.

These projections result in a headcount for direct operations of about 100 people per vehicle, a dramatic drop from current spaceflight practice.

6.2.2 Logistics

The estimates for AMLS indicate an order-of-magnitude reduction in the number of people needed in the logistics functions. Logistics cost estimates were developed using Rockwell's CLINE model which in turn is based on Shuttle orbiter experience. The model is based on both statistical and parametric relationships as well as calculations of physical measures. The logistics input variables that determine both the resources required and their associated costs are summarized in Table 6-3.

Table 6-3. Logistics Model Input Variables.

Logistics Model Input Variables
(Rick Cline's Model - All Variables are Global.)
System Name: Advanced Manned Launch System (AMLS)

Row	Variable	Booster		Orbiter		Type of Reuse	Location of Source and / or Justification	Responsible Person	Date
14	Vehicle Type	Full Reuse		Full Reuse					
15	GLOW, pounds	1,573,969		1,238,398			Rick Cline received Booster and Orbiter inputs from team members	R. Cline	
16	Payload Weight, pounds	40,000		0			Rick Cline is responsible for defaults listed in this column		
17	Solid Rocket Boosters	no		no					
18	Number of Crew Members	10		0					
19	Primary Mode of Transport, Mfgr to LS	Air		Air					
20	Distance from Mfgr to LS, miles	2,250		[illegible]					
21	Number of Operating Years	30							
22	Number of Flights/Year	10							
23	Ground Processing Duration, days	55							
24	Ground Power On Time, hours	24							
25	Flight Power On Time, hours	72							
26	Number of Personnel per Facility	13	a						
27	Depot Capability (0.0-1.0)	0.85		[illegible]					
28	Crew Life Support System Costs, $ / man-day	53,822		0			Default LCH Costs = $2,895 per man day		
29	Cryocosts - LH2, $ / pound						Currently $2.50 per pound w boiloff allowance		
30	Cryocosts - LO2, $ / pound						Currently $0.05 / pound w/o boiloff		
31	Solid RM costs, $ / pound	2.50		2.50			Currently $2.50 per pound		
32	Number of LRU Types	1,270	b	1,268	b		Shuttle = 600, Default = 300		
33	Average LRU Cost, $	250,000	c	250,000	c		Default = $75,000		
34	Average Repair Manual Page Count	75		75			Default = 75		
35	Average Repair Manual Page Cost, $	900		900			Default = $900		
36	Average Quantity of GSE per Facility	200		200			Number based on STS		
37	Average GSE Cost, $	14,500		14,500			$ based on STS Cost		
38	Labor Rate = $ / hour	27		27			$ 27 / hour, 1990		
39	Org. Maint. Man-hours per Maint. Action (MMH/MA)	24		24			Default = 10		
40	Depot Mean Time To Repair (MTTR), hours	90		90			Default = 90 hours based on STS		
41	Depot Repair Turn Around Time (TAT), days	90		90			Default = 90 days based on STS		
42	Probability of Sufficiency (POS)(0.0-1.0)	0.95		0.95			Default = 0.95		
43	System Reliability	0.98		0.98			Default = 0.975 (= 1 - Probability of Vehicle Loss)		

a = Sum (n * d) / Sum (d) where n = # of people at each of 8 facilities and d= # of days spent in each facility

b = 0.35 * 0.02 * (GLOW of Stage - Weight of Payload - Weight of Fuel)

c: Spares $ were not used on PLS and should not be used here; model does gross estimating, not precise costing.

EXAMPLE

The input values determine the manpower and supplies needed as a function of launch rate. Manpower requirements are calculated in terms of man hours and amounts of supplies (e.g.: fuel). These are convertable to dollar costs using payroll rates and supply unit costs. For a launch rate of ten per year, 1,333 personnel are shown as being needed for all AMLS logictics functions nationwide. About one-third are expected to be located at the launch site.

6.2.3 Sustaining Engineering

Extrapolating from aircraft and Shuttle experience, it should be possible to perform the ongoing Sustaining Engineering functions for a successful development with a SE staff about the same size as the direct operations crew. For the AMLS, this minimum crew is expected to be about 500 with 100 people each for the five areas of the Booster, Orbiter, Propulsion Systems, Crew/Cabin/Payload/LSS equipment, and Systems Integration. A very brief survey of experience with the STS, however, indicates that the Sustaining Engineering and Logistics functions are approximately equal numerically. Accordingly, the nominal estimate for Sustaining Engineering is set at 1000 people, approximating the off-site Logistics personnel. The high estimate is set at 1500 people. The distribution by skill categories is based on a brief review of personnel staffing patterns at Rockwell.

The logistics model has also produced estimates of spares and replacement requirements. An excerpt of this analysis is presented as Table 6-4.

The spares and replacement estimates are denominated in terms of Line Replaceable Units (LRUs). At this stage of design evolution, the LRUs are not well defined; in some cases they may be subsystems or major assemblies, in others, they may be repair kits or repair parts. The estimated numbers of LRUs required are based on reliability assessment values which project substantial improvement from current experience in many areas. This improvement, in addition to good experience with Shuttle orbiter subsystems, results in many of the Line Repairable Unit (LRU) spares being designated as safety spares, that is spare units for which the probability of normal wear-out is so low that less than one unit is projected to be required over the life of the AMLS program.

One area where less optimistic projections are used is Main Engines for the Orbiter; a total of 79 LRUs are projected based on extensive engine use. For the Booster, which uses essentially the same engine for a much briefer period during launch, only 4 LRUs are estimated to be required.

Table 6-4. Spares and Replacement Requirements.

GPOT (HRS) =	24	NUMBER OF VEHICLES =	5
FPOT (HRS) =	90	POS =	0.95
TOTAL EXPECTED FLIGHTS =	225	DEFAULT AVG. RTAT (DAYS) =	90.00
FLIGHTS/YEAR =	10	MTBR FACTOR =	1.00
		RTAT FACTOR =	1.00

PART NAME/DESCRIPTION	EQUIP TYPE	QPV	MTBR STATED	AVG RTAT STATED	REMS/ FLIGHT	REMS/ YEAR	PROGRAM REMS	RATE SPARES	CONDEMN SPARES	SAFETY SPARES	TOTAL SPARES
Wing Group			107								
Wing Body	M	1	207		0.43	4.35	97.8	1	2	NO	3
Gear Support, Fairing, Tip Fins	M	1	222		0.41	4.05	91.2	1	2	NO	3
Tail Group											
Body Group	M		52								
Hydrogen Tank	M		127								
Structure	M	1	148		0.61	6.08	136.8	1	3	NO	4
Insulation	M	1	895		0.10	1.01	22.6	0	0	YES	1
Oxygen Tank	M		599								
Structure	M	1	651		0.14	1.38	31.1	1	1	NO	2
Insulation	M	1	7,615		0.01	0.12	2.7	0	0	YES	1
Basic Structure	M		137								
Nose Structure	M	1	781		0.12	1.15	25.9	1	1	NO	2
Docking Mechanism	M	1	3,959		0.02	0.23	5.1	0	0	YES	1
Intertank	M	1	622		0.14	1.45	32.6	1	1	NO	2
Aft Adapter & Fairing	M	1	599		0.15	1.50	33.8	1	1	NO	2
MP Thrust Structure	M	1	699		0.13	1.29	29.0	1	1	NO	2
Access Panel	M	1	2,683		0.03	0.34	7.5	0	0	YES	1
Base Heatshield	M	1	2,753		0.03	0.33	7.4	0	0	YES	1
Body Flap	M	1	3,352		0.03	0.27	6.0	0	0	YES	1
Crew Cabin / Escape Module	M		391								
Crew Cabin Structure	M	1	973		0.09	0.92	20.8	0	0	YES	1
Crew Cabin Sep. System	M	1	736		0.12	1.22	27.5	1	1	NO	2

6.3 FACILITIES

AMLS Facility requirements were examined and the resultant launch site buildings are dimensioned in Table 6-5. Details of the manufacturing facilities and the launch pad were not defined. Manufacturing and long-term storage facilities are assumed to be located well away from the launch site, but all other operational activities including short-term storage are assumed to be located at the single launch site.

The launch pad is projected to be very simple. The mated AMLS vehicles will be towed to the pad on a transporter/erector which then erects the system and departs the area. The vehicles are then fueled with very few other services taking place. A simple launch tower is projected, primarily for crew access, but no other major structures.

Facilities/buildings projected for the Launch Site, assumed to be Kennedy Space Center, are:

a) Ground Operations buildings to support AMLS vehicle servicing, vehicle and payload mating, and storage

b) Flight Operations building to support vehicle flight operations and payload operations while the payload is in or near the vehicle, as well as crew training, software maintenance and development, and administration.

c) Payload Containment System building to support checkout of payloads which have been integrated elsewhere, and storage.

The Payload Containment System building is assumed to be located near the AMLS vehicle Ground Operations servicing/maintenance/ storage buildings. At this time, the co-location of these buildings appears to be a convenience rather than a necessity.

The Flight Operations building is located well away from the Launch Pad, as a blockhouse is no longer needed. This building is planned to serve both training and administrative functions as well as flight planning and monitoring.

The functional modules for the buildings are categorized as office, shop/lab, and hangar modules. The offices must be air-conditioned, the while shop/lab modules must be capable of being clean-rooms (clean) and therefore air-conditioned. The requirements for the hangar modules need further assessment. Current aircraft practice is open hangars; if a clean operations are needed, this is accomplished with temporary structures and/or tenting. The AMLS may be able to maintain limited clean areas with the tunnel designs similar to those chosen for the Personnel Launch System (PLS). If the entire hangar module must be clean, provisions for airlocks and clean air-conditioning will substantially impact construction costs.

Table 6-5. Facility Descriptions.

WBS Number & Description	Typical Equipment	Dimensions	Qty	Dimensions-High	Qty	Dimensions-Low	Qty	Site Acreage	Equipment = E Estimate Needed?	Location of Source and/or Justification	Responsible Person	Date
- 3.3 Facilities												
- 3.3.1 Payload Containment Facility												
- 3.3.1.1 PCS Acreage											Lorch	9/6/91
- 3.3.1.2 PCS Building (Hanger Construction)								3 acres on HPF lot				
- 3.3.1.2.1 PCS High Bay	Cranes	85'W x 165'L x 85H	1	120'W x 170'L x 85H	1	75'W x 110'L x 85H	1					
- 3.3.1.2.2 PCS Airlock	Cranes	86'W x 70'L x 85H	1	86'W x 70'L x 85H	1	50'W x 65'L x 85H	1			Drawing		
- 3.3.1.2.3 PCS Offices w A/C	Desk Computers	40'W x 100'L x 20H	1	40'W x 100'L x 20H	1	40'W x 75'L x 20H	1					
- 3.3.1.2.4 PCS Shops w A/C	Mach Tools, Test Eq	30'W x 165'L x 20H	1	30'W x 170'L x 20H	1	60'W x 90'L x 20H	1					
- 3.3.1.2.5 PCS Storage	Cranes	55'W x 135'L x 85H	1	55'W x 190'L x 85H	1	80'W x 90'L x 85H	1					
- 3.3.1.3 Functional Area Mission Equipment	Payload Equipment List Not Developed								E			
- 3.3.2 Horizontal Processing Facility												
- 3.3.2.1 HPF Acreage											Lorch	9/6/91
- 3.3.2.2 HPF Buildings (Hanger Construction)								10-20 acres				
- 3.3.2.2.1 HPF Processing Bays	Cranes	200'W x 275'L x 67H	4	200'W x 275'L x 67H	4	200'W x 275'L x 67H	4					
- 3.3.2.2.2 HPF Storage Bays	Cranes	200'W x 250'L x 47H	6	200'W x 275'L x 47H	8	200'W x 250'L x 47H	5			Drawing		
- 3.3.2.2.3 HPF Mating Bays	Cranes	225'W x 250'L x 128H	3	225'W x 250'L x 128H	3	225'W x 250'L x 128H	2					
- 3.3.2.2.4 HPF Shops w A/C	Mach Tools, Test Eq	40'W x 250'L x 20H	2	40'W x 250'L x 20H	2	40'W x 250'L x 20H	1					
- 3.3.2.2.5 HPF Offices w A/C	Desk Computers	40'W x 250'L x 20H	2	40'W x 250'L x 20H	2	40'W x 250'L x 20H	1					
- 3.3.2.3 Functional Area Mission Equipment	See GSE List								See GSE List			
- 3.3.3 Launch/Mission Control Center												
- 3.3.3.1 L/M Acreage											Langer/Earhart	
- 3.3.3.2 L/M Building								3 Acres (Separate)				9/10/91
- 3.3.3.2.1 L/MB Ground Floor Lab/Office w A/	Desk Computers	140'W x 140'L x 12H	1	140'W x 180'L x 12H	1	100'W x 100'L x 12H	1			Drawing		
- 3.3.3.2 L/MB Upper Floor w A/C	Desk, Mission Comp's	140'W x 140'L x 12H	2	140'W x 180'L x 12H	2	100'W x 100'L x 12H	2					
- 3.3.3.2 L/MB Training Area w A/C	Flt Simulators, Water Tank	80'W x 140'L x 30H	1	140'W x 180'L x 30H	1	80'W x 100'L x 30H	1					
- 3.3.3.3 Functional Area Mission Equipment	Simulator Laboratory Equipment & Computers; 0-G Training (Water Tank); 1-G Training Equipment								E			
- 3.3.4 Launch Pad		Not Studied										
- 3.3.4.1 Pad Acreage												
- 3.3.4.2 Pad Building		May not have building, only										
- 3.3.4.3 Functional Area Mission Equipment	Transporter/Erector Fuel Storage Facility Fueling Equipment	Launch Support Tower							E			
- 3.3.5 Landing Site		Probably can use existing STS runway										
- 3.3.5.1 Landing Acreage		May need new safing/venting pad adjacent to runway.						1 Acre (additional)				
- 3.3.5.2 Landing Building		No need for new buildings identified.										
- 3.3.5.3 Functional Area Mission Equipment	See GSE List								See GSE List			

Ground Operations equipment for the AMLS is projected to be similar to equipment developed for aircraft. Electronic test equipment will be selected from that used to maintain avionics now being developed and modified to match the changes needed for the AMLS. Only minor development efforts are projected for this test equipment. Scaffolding and mechanical equipment will probably require shape modifications from existing equipment, but only appearance factors will change.

The Shuttle equipment list was reviewed to project AMLS equipment functional requirements based on five flight vehicles and ten flights per year. The equipment is described in Table 6-6 by a brief name tag and an estimate of the equipment sets needed at specific locations. Pending later detailed analysis of the AMLS requirements in view of the planned use of BITE, this list is expected to provide a good basis for projecting AMLS costs from Shuttle practice. While the equipment descriptions do not provide sufficient detail to provide an independent cost estimate based on the equipment's physical description, the list should be valuable in future detailed trade studies to determine the paths to follow in selecting Ground Support Equipment investments. Based on this Shuttle, it appears that GSE investments are relatively small in relation to the Ground Crew costs and larger investments are justified if they can reduce the crew cost.

6.4 SOFTWARE

Estimates of the size (in lines of code) for some of the AMLS software are given in Table 6-7. Software for the AMLS represents an area of moderate risk because the physical systems which the software will control and/or monitor are not well defined. Progress in software, computers, sensors and control mechanisms over the next ten to twenty years is expected to build a sufficient base that much of the AMLS software will be modified and/or tailored standard software. It is expected to evolve directly from standard aircraft software and represent about the same level of effort as adapting existing flight software to a new aircraft. This contrasts dramatically from the Shuttle experience where two separate developments were undertaken for the regular and backup flight software and informal Rockwell estimates for the entire industry and government effort for Shuttle flight software are about $1 billion in "as spent" dollars.

Software for the Health Monitoring System represents a substantial development cost risk because the smart sensors designated for this application have not yet been defined and most have not been developed. It is reasonable to project that some of the Health Monitoring System software for the AMLS will evolve from aircraft development efforts over the next decade. Health monitoring software for the STS Main Propulsion System is already being pursued, and it is reasonable to project that the technology will be well understood by the time of the AMLS Phase C/D effort in the year 2000.

Table 6-6. Equipment Descriptions.

WBS N	Location	Equipmemt Description	Used On System	STS Model	LE	PB	SB	MB	PCPF	PAD
		Ground Support Equipment List			----- Number of Units at each Facility-----------					
2.6.8	Processing B	RCS PRIMARY ENGINE THROAT PLU(	PROP	A70-0798	0	4	8	0	0	0
2.6.8	Processing B	RCS VERNIER ENGINE THROAT PLUC	PROP	A70-0799	0	4	8	0	0	0
2.6.8	Processing B	OMS ENGINE THROAT PLUG SET	PROP	A70-0950	0	6	0	0	0	0
2.6.8	Processing B	OMS ENGINE INTERFACE CLOSEOUT	PROP	A70-0955	0	2	0	0	0	0
2.6.8	Processing B	MPS PORTABLE REGULATOR TEST E	PROP	C70-0743	0	2	0	0	0	0
2.6.8	Processing B	PROPELLANT GAUGING TEST SET	PROP	C70-0753	0	2	0	0	0	0
2.6.8	Processing B	RCS PRIMARY AND VERNIER INJ INSI	PROP	C70-0799	0	2	0	0	0	0
2.6.8	Processing B	VOLUMETRIC LEAK DETECTOR	PROP	C70-0888	0	2	0	0	0	0
2.6.8	Processing B	MPS COMPONENT FLOW TESTERS (-	PROP	C70-0903	0	2	0	0	0	0
2.6.8	Processing B	MPS INTERNAL INSPECTION SET	PROP	C70-0907	0	2	0	0	0	0
2.6.8	Processing B	MPS TEST ADAPTER SET	PROP	C70-0914	0	4	0	0	0	0
2.6.8	Processing B	PROPULSION SYS VALVE LEAKAGE [	PROP	C70-1536	1	1	0	0	0	1
2.6.8	Processing B	OMS/RCS QD TOOL AND CAP SET	PROP	F70-0031	1	1	0	0	0	1
2.6.8	Processing B	OMS ENGINE INSTALLATION FIXTURI	PROP	H70-0515	0	2	0	0	0	0
2.6.8	Processing B	MPS LRU COMPONENT INSTALLER	PROP	H70-0528	0	2	0	0	0	0
2.6.8	Processing B	MPS ENG INSTALLATION INSTALLER	PROP	H70-0568	0	2	0	0	0	0
2.6.8	Processing B	HANDLING ADAPTERS MPS COMPON	PROP	H70-0703	0	2	0	0	0	0
2.6.8	Processing B	HYSTER LIFT TRUCK (HORIZONTAL II	PROP	H70-0764	0	2	0	0	0	0
2.6.8	Processing B	MPS HEAT SHIELD HANDLING SLING	PROP	H70-0852	0	2	0	0	0	0
2.6.8	Processing B	MPS MOVER (WHILE INSTALLED) SET	PROP	H70-0890	0	1	0	0	0	0
2.6.8	Processing B	MPS TRANSPORT DOLLIES (HORIZ)	PROP	H70-0901	0	8	0	0	0	0
2.6.8	Processing B	MPS HANDLER SLING	PROP	H70-0902	0	2	0	0	0	0
2.6.8	Processing B	MPS ROTATING SLING	PROP	H70-0903	0	1	0	0	0	0
2.6.8	Processing B	MPS LRU INSTALLER / COMPONENT I	PROP	H70-0905	0	2	0	0	0	0
2.6.8	Processing B	MPS INTERFACE SUPPORT PANEL	PROP	H70-0911	0	2	0	0	0	0
2.6.8	Processing B	MPS ENVIRONMENTAL PROTECTIVE	PROP	S70-0902	0	20	40	0	0	0
2.6.8	Processing B	TANKAGE MOISTURE MONITORING U	PROP	S72-1080	0	4	0	0	0	0
2.6.8	Processing B	RCS / OMS THRUSTER WORK FIXTUF	PROP	XXX-2	0	6	0	0	0	0
2.6.8	Processing B	MPS WORK FIXTURES	PROP	XXX-20	0	5	0	0	0	0
2.6.8	Processing B	MPS HANDLER / MOVER	PROP	XXX-21	0	2	0	0	0	0
2.6.8	Processing B	RCS / OMS THRUSTER HANDLING DO	PROP	XXX-3	0	6	0	0	0	0
2.6.8	Processing B	GN2 THRUSTER COVER SET	PROP	XXX-4	0	3	3	0	0	0
2.6.8	Processing B	MPS DOLLY (VERTICAL OFF VEHICLE	PROP	XXX-43	0	5	0	0	0	0

Substantial portions of the Ground Operations software can be assembled from modules which have already been developed for military and civil aviation. The degree to which existing software modules can be incorporated needs further study as the tentative estimates developed in this study provide only rough estimates of the size of the programs, and (in a very few cases) the time needed to develop them under the assumption that most of the code would be new.

Software for flight/mission design and control represents a substantial body of code. Much of the fundamental design work in this area has been accomplished for the Shuttle program, and this area continues to evolve. One of the future trade analyses for the AMLS will address the question of how much of this evolving body of code should be adapted and how much should be developed new.

Table 6-7. Software Descriptions.

WBS Number	WBS Description / Software Description	Low	.... Software Lines of Code .... Nominal	High	Development Time	Comments	STS Equiv SLOC	Responsible Person	Date
3.3.1	FLIGHT / MISSION SOFTWARE								
3.3.1.1	GNC Software		50 K - Includes Contingency		18 months	About 40% Recycled Code; About 50% Common to Stages			
3.3.1.2	Health Monitoring Software		Not Yet Determinable		Developments	Smart sensors have not been developed yet; their software is part of development.			
3.3.1.3	Payload Interface Software					Tentative estimates - topic not well studied			
3.3.1.3.1	Payload Test Programs		500 K						
3.3.1.3.1	Payload Measurements Database		300 K						
3.3.2	GROUND SOFTWARE								
3.3.2.1	Flight Operations Software								
3.3.2.1.1	Operations Support-Plan & Schedule		200 K - Mod Commercial			Future trade study: major new development vs recycle old modules			
3.3.2.1.2	Flight Design, Analysis, Cmd & Timeline		1820 K - Some COTS			Should be able to use commercial software			
3.3.2.1.3	Communication & Data Distribution		200 K - Mod Commercial			Development should benefit substantially from ongoing investment in simulator softw			
3.3.2.1.4	Simulation & Training Software								
3.3.2.1.4.1	Simulation & Training Software		650 K						
3.3.2.1.4.2	Simulation Procedures & Applications		100 K						
3.3.2.1.4.3	Simulation Procedures Database		500 K						
3.3.2.2	Maintenance Operations Software								
3.3.2.2.1	Operations Support-Plan & Schedule		200 K - Mod Commercial			Mostly associated with test equipment development-should have significant modulari			
3.3.2.2.2	Test Equipment Software		1600 K			Should be able to use modified aircraft modules			
3.3.2.2.3	Health Monitoring Data Evaluation		Modified Commercial			Should be very similar to 3.3.2.1.3			
3.3.2.2.4	Communication & Data Distribution		200 K - Mod Commercial			Should be able to modify aircraft software			
3.3.2.2.5	Simulation & Training Software		200 K						
3.3.2.3	Flight Test Program Software		????? - See Comment			The Health Monitoring System will collect data normally collected in the test program Need for Flight Test Software is not established.			
3.3.3	Support Software					Unique software may not be justifiable.			
	Administrative								
	Accounting		COTS & Mod COTS						
	Terminal Network		COTS & Mod COTS						
	Library		COTS & Mod COTS			Unique software may not be justifiable.			
	Logistics								
	Management		300 K - Mostly COTS						
	Database		300 K - Mostly COTS						
	Applications		COTS & Mod COTS			Existing and/or STS software should need minor modifications			
	Weather								
	Applications		300 K						
	Database		300 K			Existing and/or STS software should need minor modifications			
	Range Tracking & Safety								
	Applications		800 K						
	Database		600 K						

Software for the maintenance test equipment will represent a substantial part of the investment in test equipment, much of which will be unique to the AMLS. The current practice of developing software in conjunction with the hardware provides the reasonable expectation that in the next decade there will be a design base of hardware/software modules in test equipment that is analogous to the modules ("cards") available for personal computers. The availability of such a design base would substantially reduce the effort needed to design specialized test equipment/software.

Flight test software is normally expected to be a major task. For the AMLS, however, the Health Monitoring System collects the information that would now be collected only during the flight test phase. Accordingly, no estimates for software are provided pending determination of a requirement for flight test information that would not otherwise be collected.

Support Software modifications will be needed, but no major new developments have been identified. Administrative software should emphasize off-the-shelf software, not only because the procurement and installation costs are much lower than for unique software, but also because commercial packages are maintained and updated frequently, and replacement of outdated packages is facilitated. Weather, range tracking, and safety software will need to be updated for the AMLS, but major rewrites should not be attributed to the AMLS alone.

6.5 COMPLEXITY INFORMATION

The variables shown in the previous tables are the physical and programmatic characteristics that drive the GE PRICE cost model. This model is widely used in government and the aerospace industry. It has the capability to address the subjective topics of complexity /difficulty and technological challenge quantitatively through expert opinion assessments of the capability of the design team and difficulty of the challenge. While some of the input variables for GE PRICE such as weight, are readily determined, others are subjective and/or require information which is not usually documented at this early phase of program evolution. Tables 6-8a, b, and c are copies of worksheets used for collecting this information.

The first of these sheets collects some of the general or readily available information, and documents estimates of the technology status of the subsystem and/or components. Also collected here are estimates of the design team's experience/expertise; the expected difficulty of integrating the subsystem; and any special tooling requirements. The next two worksheets are designed to provide information that permits an independent quantitative estimate of complexity to be determined. These Worksheet forms were developed to collect and document subsystem characteristics which are used to determine the manufacturing complexity. Two different worksheets are needed as the GE PRICE program considers subsystems to be composed either of structural/mechanical assemblies or electronic assemblies. These forms relate characteristics known to designers fairly early in the design process to the quantified experience base in the PRICE program.

Table 6-8a. GE PRICE Data Collection Worksheet-General Information, Technology, Design, Integration, and Tooling.

WBS NUMBER: ________________ WBS NAME: ________________________

ASSEMBLY/COMPONENT NAME/DESCRIPTION: ____________________________
____

ANALOGOUS SUBSYSTEM: ____

QUANTITY NEXT HIGHER ASSEMBLY: ________
STRUCTURAL WEIGHT: __________
TOTAL WEIGHT: __________

TYPES: __________
ELECTRONIC WEIGHT: __________
ELECTRONIC DENSITY: __________

TECHNOLOGY:

TECHNOLOGY LEVEL AT PRESENT TIME:

___ LEVEL 1: BASIC PRINCIPLES OBSERVED AND REPORTED
___ LEVEL 2: CONCEPT DESIGN FORMULATED
___ LEVEL 3: CONCEPTUAL DESIGN TESTED ANALYTICALLY OR EXPERIMENTALLY
___ LEVEL 4: CRITICAL FUNCTION/CHARACTERISTIC DEMONSTRATED
___ LEVEL 5: COMPONENT/BREADBOARD TESTED IN RELEVANT ENVIRONMENT
___ LEVEL 6: PROTOTYPE/ENGINEERING MODEL TESTED IN RELEVANT ENVIRONMENT
___ LEVEL 7: ENGINEERING MODEL TESTED IN SPACE
___ LEVEL 8: FULL OPERATIONAL CAPABILITY

YEAR OF FIRST PRODUCTION: __________
DESCRIPTION OF TECHNOLOGY ISSUES:

____

WHERE/HOW WORKED:

____

TECHNOLOGY DEVELOPMENT NEEDED:

____

DESIGN, INTEGRATION & TOOLING:

DESIGN DIFFICULTY:
___ DESIGN EXISTS
___ MODIFIED DESIGN
___ SIMPLE
___ ROUTINE (NOMINAL)
___ DIFFICULT
___ ADVANCED
___ TECHNOLOGY / DESIGN SSUE

EXPERIENCE OF DESIGN TEAM:
___ EXPERT
___ NORMAL
___ MIXED NEW / OLD
___ NEW

INTEGRATION DIFFICULTY:
___ NONE
___ SIMPLE
___ MODERATE
___ ROUTINE
___ DIFFICULT
___ VERY DIFFICULT

INTEGRATION:

WHAT DOES THE SUBSYSTEM / ASSEMBLY / COMPONENT INTERFACE WITH OR NEED TO BE INTEGRATED WITH? (INCLUDE SOFTWARE AS A POTENTIAL INTERFACE ITEM):

____

UNUSUAL TOOLING / TEST EQUIPMENT:

Table 6-8b. GE PRICE Data Collection Worksheet-Structural Manufacturing Complexity.

MCPLXS VALUE ________

WBS No: ________________ WBS Name: ________________________________

Name / Description / Analogy ________________________________

| Weight | Number of Pieces | ________________________________

Description of Element	Process Description & Accuracy	% Process	Type of Material & Accuracy	% Material	% New Design	% Design Repeat or Symmetry	% Make	% Off Shelf	Need Man Rating

Categories	Categories	Categories
	Metals	
Antennas | Engines & Motors	Sheet Metal (SM) Fabrication	Aluminum Alloy
Drive Assemblies	Machine Cast, Extrusions < 10 mils	Magnesium
mWave Transmission	Machine SM, Plate, Bar < 10 mils	Brass/Bronze/Copper
Optics | Fuses	Machine SM, Plate, Bar 2 - 5 mils	Iron / Steel
Servo Mechanisms	Machine SM, Plate, Bar < 2 mills	Stainless Steel
Machine Tools		Titanium
Printed Circuit Boards	Composites	Cobalt
Cabling | Batteries	Composite Struts, machined	Nickel
Gyros - Inertial	Honeycomb with machined inserts	Molybdenum

Table 6-8c. GE PRICE Data Collection Worksheet-Electronics Manufacturing Complexity.

MCPLXE VALUE: ______

WBS No: ____________ WBS Name: ____________

Name / Description / Analogy ____________

| Wt Electronics | Wt Structure |

Type of Electronics	% Type	% Discrete	% IC's	% LSI	% Hybrid	% VLSI	% New Design	% Design Repeat or Symmetry	% Make	% Off Shelf	Need Man Rating
Analog - Receivers, Amps, Audio, Video											
Digital-Computers Gates, Registers, Counters, Buffers											
Display with CRT-TV monitors, Radar screens, Scopes											
Display w/o CRT-LCD, LED, Indicator panels											
Transmitters -hi power											
Power Supply rectifiers and regulators											
	100%										

Categories:

Discretes - transistors, resistors, capacitors, diodes, etc.

ICs - Integrated Circuits - 1 to 100 gates

LSI - Large Scale Integration - 100 to 1000 gates

Hybrids - thin / thick film substrates with unpackaged ICs, LSIs or VLSI devices

VLSI - Very Large Scale Integration - 1000 to 1,000,000 gates

Table 6-8c. GE PRICE Data Collection Worksheet-Electronics Manufacturing Complexity.

7.0 TECHNOLOGY ASSESSMENT

This section documents the results of the technology assessment task. This task had the overall objective of identifying and selecting applicable technologies that enhance AMLS goals to achieve minimum life cycle costs (LCC). Technologies with minimum development risk for efficient and cost effective AMLS system design, manufacturing, maintenance and operations are the prime candidates for our selection process. To facilitate the AMLS technology identification process, more than 200 candidate technology topics that are considered relevant to AMLS were compiled from a comprehensive list of sources.

Our current database has essentially been built on the prior technology screening effort performed for the PLS. In addition, the Single Stage to Orbit (SSTO), Assured Crew Return Vehicle (ACRV) and Advanced Launch System (ALS) studies have generated significant technology data applicable to the AMLS. The NASP program, currently in Phase 2D, has a comprehensive technology maturation program. Many of these evolving technologies, such as high temperature, high performance structures, hydrogen/oxygen RCS and OMS and high power density fuel cells will attain fairly mature status before the mid 1990's. Valuable generic research data has been found on aircraft services and maintenance from the Air Force Office for Technology Application documents and SDIO Technology Applications Information Systems.

On the basis of a comprehensive technology database and the selection criteria for the AMLS, a list of the applicable technology options/alternatives has been identified for the major WBS elements. A thorough review has been conducted of the technology maturation programs being actively pursued by the National Aero-Space Plane (NASP) program and have selected specific applicable technology items for AMLS system design trades. A simple technique for monitoring and tracking the status of applicable technologies has been devised to aid in the formulation of the AMLS advanced development schedule requirements and technology plans.

Key technology development requirements in six specific technical areas deemed critical to the AMLS have been investigated. Assessment revealed that some of these technologies are unique and unproved and have fairly low technology's readiness levels. Backup technology alternatives were identified if the development of any of the key technologies could not meet the AMLS schedule requirements.

For the nine key technologies that have been selected from the six technical areas for having the highest payback potential uniquely for the AMLS, detailed technology development plans have been developed. These plans show the time schedules necessary to bring the respective technology to proper level of maturity to meet the AMLS program requirements. ROM program funding cost estimates for these nine critical technology development programs have been made and are presented in this report.

7.1 TECHNOLOGY IDENTIFICATION AND ASSESSMENT

The timely identification and development of key technologies is essential for all advanced aerospace initiatives. To support of the design and development of the AMLS, major advancements in technology of materials, structure sciences and reusable low cost propulsion systems are required. Many of these technologies are nominal extensions of the proven design. They are either available now or will attain acceptable levels of maturity through the ongoing, related technology development programs. However, some technologies to satisfy the designed needs of the AMLS are unique and will require dedicated advanced development efforts.

7.1.1 Technology Selection Approach

The technology readiness levels (TRL), as defined by NASA and shown in Figure 7-1, are presented as a convenient reference. The numerical scale and its descriptors provide a well-known and recognized measure of the status of an advanced development program and the maturity of its technologies. Our approach to the technology selection process is to monitor and identify applicable evolving technologies that have a projected NASA technology level of 6 by the year 2000. Technologies with this level of maturity pose minimum development schedule and cost risk to the AMLS. The focus is on the enhancing technologies that can effectively reduce AMLS life cycle costs. To accomplish this objective, the major emphasis of our effort is placed on the identification and selection of technologies that will lead to:1). significant improvements in system performance, reliability, safety life, 2). each of hardware fabrication, assembly, inspection, ground processing and flight operations, and 3). improved system maintainability, checkout and turn-around capabilities.

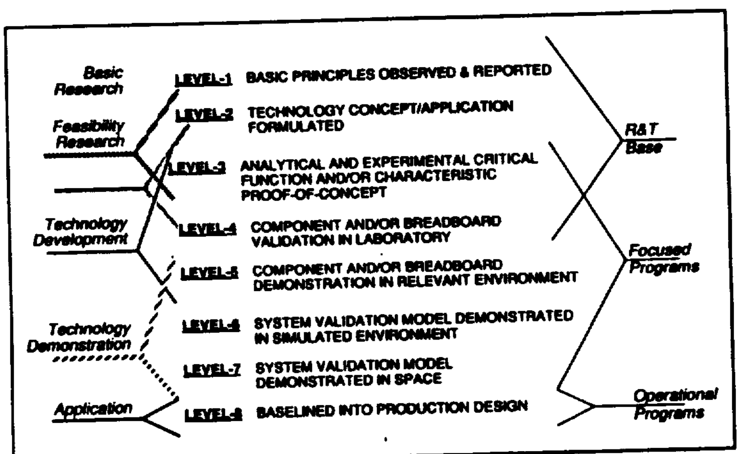


Figure 7-1. Technology Readiness Levels And Program Phases

7.1.2 AMLS Technology Options

The applicable technology options identified for the major WBS elements are shown in Table 7-1. Many of the structural material selections for the body group are similar to the PLS and present no technology issue. The application of high temperature metal alloy for the booster wing structure has only limited space experience and the fabrication of titanium aluminide structures is in the early stages of development. Aluminum-lithium has a significant strength/weight advantage compared to conventional aluminum alloys. It is an attractive option for the thrust structure and for the lower orbiter structure. The ductility and weldability of this material are issues being investigated.

Smart Structures is a fast evolving technology that holds promise to revolutionize the next generation of structural design for aerospace vehicles. Advanced optical sensors are embedded in the structure for material strain measurement. Active sensing enables detection of dynamic changes in the properties of the materials at critical airframe locations . This concept, which is in the early laboratory verification stage, is intended to improve vehicle life cycle/aging predictions to facilitate logistics support and vehicle maintenance.

Cryogenic tank insulation is the foremost design issue for the AMLS propellant tank. The viability of applying the insulation system inside and outside the pressure vessel has been investigated. The concept of using foam insulation (Rohacell) bonded on the external surface of the cryogenic tank has been experimentally verified. However, the reliability of these materials has not been demonstrated.

The use of advanced metal encapsulated multilayer insulation (MLI) as a thermal protection system on the internal surface of the cryogenic tank is only in the laboratory development stage. The MLI has shown outstanding thermal performance at cryogenic temperature. The fabrication of the MLI panels involves complex and costly processes. In addition, the method to join the individual MLI panel to form an integrated insulation system is an issue for further development.

The design of the reaction control propulsion system and orbit maneuvering propulsion system using cryogenic hydrogen and oxygen as propellants is based on fairly mature technology. Specific options associated with the selection of (1) either a liquid or a gaseous feed system for the Ground and flight processing systems for the AMLS must incorporate advanced automation and RCS thrusters, or (2) either a pressure-fed or a turbopump-fed system for the OMS engine is a design issue that can be resolved in further tradeoff evaluation. The Integrated Hydrogen/Oxygen Technology (IHOT) study performed by Rockwell's Space System Division for NASA/Lewis Research Center in 1989 provides a useful technology reference.

Avionics elements defined for the AMLS present no particular technology issues. The system will require advancements in architecture design and in sophistication of data processing, health monitoring, failure detection, diagnostics and reconfiguration management and controls. Advanced concepts of using neural network and fuzzy logic to provide added intelligence and autonomy for more effective control of the AMLS will be subjects for further technology assessment studies.

Table 7-1a. Technology Options.

WBS Element	Options	Technology Status & Issues
Wing Group - Structure Booster	Aluminum Alloy Composite - Graphite/Polyimide	Temperature Capability Limited, TPS Required. Highest Temperature Capability. Well Characterized Material. Early Quality Problems Under Control.
Orbiter	High Temperature Metal Alloy Columbium Alloy Aluminum Alloy Titanium Aluminide Titanium Composite - Graphite Polyimide	Back-up Option To Assure Multiple Reuse. Heavy - Limited Space Experience. Temperature Capability Limited, TPS Required. Early Development. Low Ductility & Low Fracture Toughness. Welding Demonstrated. SPF/DB Demonstrated. Heat Resistant to 1000°F. Difficult to Fabricate.
Wing TIP FIN	Graphite/Polyimide Titanium Aluminide Aluminum Alloy	High Temperature Capability. Early Development. Temperature Capability Limited, TPS Required.
Body Group Primary Structure Thrust Structure	Aluminum Alloy 2024 Aluminum - Lithium Alloy Silicon Carbide/Aluminum Titanium Aluminide	Substantial Mfg. Experience - Lowest Cost. Limited Experience, 10% Higher Strength, Lower Weight Than Al. Lower Weight & Higher Costs. Developmental & Very Expensive.
Secondary Structure Crew Cabin Access Tunnel Payload Containment	Aluminum 2219 Aluminum Alloy Honeycomb Aluminum - Lithium Alloy Graphite/Polyimide	Substantial Mfg. Experience - Lowest Cost. TPS Required. Limited Fabrication Experience. Alternative Material, Lower Weight, High Cost.
Lower Orbiter Structure	Al Alloy or Al-Li Graphite/Polyimide Thermoplastics Titanium Aluminide	Requires Thick TPS. Gr/Pi Structural Repair Method, Structural Adhesive Require Certification. Not As Mature As Gr/Pi. High Fabrications Cost
Cryogenic Tank Tank	Aluminum Alloy Graphite/Epoxy	Limited Experience Being Developed for NASP Non-Integral Tank
Intertank	Aluminum-Lithium (Booster) Graphite/Peek (Orbiter)	Limited Experience Lower Weight. Being Developed for Aircraft
Smart Structures	Structure Integrity Monitor Trend Data Acquisition	Optical Sensors Embedded in Structure for Strain Measurement in Development - Rockwell Science Center. System Inspection Checkout and Repairability are Potential Issues.

Table 7-1b. Technology Options (Continued).

WBS Element	Options	Technology Status & Issues
Cryogenic Tank Insulation Internal	MLI	Demonstrated at Low Tank Pressure. High Thermal Efficiency; Inspection and Repair are Issues.
	Foam Block	Requires Development. Reusability Not Demonstrated. Requires Impermeable Membrane - Not Developed. Block Bonding To Tank Not Inspectable.
External	SOFI	Reusability Not Demonstrated
	Foam Block	Significant Development Undertaken.
Thermal Protection System (TPS) Body Protection Lower Surfaces	HTP-6 (FRC) Tile	Hardened for Durability, Permanent Water Proofing.
	Stratified Density Tile Carbon/Silicon Carbide, SiC/SiC	Lower Maturity, Costs Similar to FRCI. Much Lower Maturity.
	Metal Tiles	Early Development.
Side & Upper Surface	AFRSI Blankets, (Direct Bond) Other Blankets, Tiles Available As Alternatives	Existing Orbiter Blanket Technology.
Nose & Leading Edges	Carbon/Carbon (ACC) (Fasteners)	Upgraded Orbiter Technology
	Carbon/Silicon Carbide (C/SiC)	Being Developed for Hermes, Candidate for Performance Enhancement.
	Reinforced Ceramics High Temp Metal Alloy (Nb)	Early Development.
Attachment Methods	Metallic Fasteners For Leading Edge	No Technology Issues
	Direct Bond Adhesive(s)	Available to -600°F and Need Certification. Strain Isolation Pad (SIP) Needed For Al-Li.
	Mechanical Fasteners	Design Challenge.
Landing Gear Nose Gear (Braking & Steering) Main Landing Gear (Braking)	Electric	Enhanced System Reliability Advanced Development of High Power EMA, EHA, & Switching Controls Required.
	Hydraulic	Hydraulics Involves Complexity & Checkout Requirements. Leaks are a Problem
Propulsion - Reaction Control System	Cryogenic H2 & O2	High Performance. Technology Fairly Mature.
Orbit Maneuvering System	Cryogenic H2 & O2	Liquid vs. Gaseous Feed System Selection Issue. Liquid Thruster Has Performance & Weight Advantage Pressure vs. Turbo-Pump Fed System Selection Issue.

Table 7-1c. Technology Options (Continued).

WBS Element	Options	Technology Status & Issues
Prime Power	Primary Batteries (Lithium Thionychloride)	High Power Density, Not Rechargeable
	Secondary Batteries (Ag-Zn)	Mature Technology. High Weight, Limited Cycle LIfe.
	H2/O2 APU	Maturity 2-3, Complex, Low Reliability
	Fuel Cell (Modified Orbiter)	System Complexity. High Energy Capability.
	High Power Density Fuel Cells	Technology Maturity at Level 3.
Electric Distribution	Low Voltage 28 Vdc	High Weight, mature (TL 8)
	High Voltage 130 V DC	Low Weight, Being Developed for SSF.
	270 V DC	Low Weight, Being Developed for NASP.
	AC	Not Being Considered.
Actuators	Electromechanical (EMA)	System Simplicity & Reliability. Low Power (20 HP) Actuator Qualified.
	Electrohydrostatic (EHA)	High Power Actuator and Switching Control Equipment Require Advanced Development.
Avionics GN&C	Autonomous with Pilot Backup	Architectural & Design Issues.
Comm. & Tracking		No Technology Issues.
Data Processing		Parallel Processing, VLSI Techniques.
Health Monitoring. & Diagnosis.		
Displays & Controls	Head-up Display (HUD)	No Technology Issues.
Software:	High Order Languages ADA/Expert Systems	
	Neural Network	Early Development - Rockwell Science Center.
	Fuzzy Logic	Applications Being Investigated.
Antennas	Embedded	EM Transparency Questionable.
	Deployable	Deployable is Backup Design, mechanical Complexity.
Cooling System	Passive (Avionics)	May Be Marginal, Heat Sink Capacity Limited, Ready Technology
	Active	Integrated with Environmental Control System.
	Cryogenic Heat Sink	MPS Residuals Available, Being Developed for NASP.
Environmental Control Radiator	Body Mounted (Freon)	Liquid Loop Mature Technology.
	Deployable (Freon)	More Complex, Highly Efficient (Heat Pipe, 2-Phase Thermal Transport Loop). Advanced Solid (High Conductance) Radiator in Laboratory Development.
Heat Transfer Loop	Cryogenic Heat Sink	Being Developed for NASP.
	1 Fluid Loop (H_2O)	No Technology Issues.
	2 Fluid Loops (Freon & H_2O)	More Complex Servicing and Checkout Requirements.
Personal Provisions	Galley (Hygiene)	Improved Waste Management System Required. Development and Verification for Zero-G Required.

Table 7-1d. Technology Options (Concluded).

WBS Element	Options	Technology Status & Issues
<u>Escape Systems</u>		
Propulsion System	Solid Rockets Hybrid Propulsion	No Technology Issues. Hybrid Development, LO2 Common with Fuel Cell.
Recovery Systems	Parachutes (Water Landing) Abort Parameter Sensors and Autonomous Controls	Passive Aero-Stability of Capsule Verified. Smart Sensors and Intelligent Adaptive Expert Control System Development and Demonstration required.
<u>Operations</u>		
Ground Processing	Automated Checkout Systems Auto Ground Processing Expert Systems Auto Logistics Planning Expert Improved Weather Protection On Ground	At or Very Near the State-Of-The-Art. Architectural and Design Issues, But Not Technology Development Issues.
	Gas Leak Detection System	Ultra Accurate Multiple Gas Sensors in Development.
Mission (Flight) Processing	Automated Mission Control Systems Auto Launch Control Expert Systems Advanced Lightning Protection On Ground and In Flight	At or Very Near The SOA. Architectural and Design Issues, But Not Technology Development Issues.

An advanced heat exchanger that permits the use of cryogenic hydrogen as the heat transfer fluid is being developed for the National Aero-Space Plane for the environmental thermal control subsystem. The prototype hardware has been tested and verified and showed exceptionally high performance in heat transfer effectiveness. It is a candidate technology for AMLS consideration if the on-board cryogenic hydrogen can be used as the heat sink fluid.

Ground and flight processing systems for the AMLS must incorporate advanced automation and control techniques to facilitate checkout, launch preparation and turn-around operations. Advanced sensor technologies such as ultrasonic flow meters, flyable high frequency signal processors and multispectral, high resolution imaging leak detection systems, are being investigated by NASA, DOD and private industries. Operational prototype hardware for some of the systems is projected by 1995 and the flight qualified system by 1997.

To supplement the information presented in Table 7-1, a more detailed compilation of the TPS materials/structure technology options has been made. It has been used for trade studies leading to the Task 3 reference system. The data showing the TPS options, the maximum operating temperatures of these materials, the technology status information and potential development issues, are summarized and presented in Table 7-2.

The prime TPS material options for the vehicle nose and leading edge structure elements includes carbon-carbon, carbon/silicon carbide (C/SiC), and silicon carbide/silicon carbide (SiC/SiC). SiC/SiC has the highest allowable temperature of 3200 deg F. However, the material might require a coating, i.e., reaction cured glass (RCG), that works in the intermediate temperature (1600-2000 deg F) regime to prevent potential atmospheric oxidation degradation effects. It is noteworthy that carbon/silicon carbide has been selected as the TPS material and is being developed for the European Hermes program.

For the AMLS vehicle lower surfaces, the various material options are listed in five categories based on their physical characteristics and specific structure makeup.

Recent development programs conducted by Thermal Sciences Division, Thermal Protection Materials Branch (TPMB) of NASA Ames Research Center have demonstrated that Alumina Enhanced Thermal Barrier (AETB) tiles can be made to withstand surface temperatures of 3000 deg F. In addition, further progress is being achieved in making tiles with Hafnium and Zirconium fibers that may work at temperatures approaching 4000 deg F.

For the lower heat load surfaces, it may be desirable to use the lightweight flexible insulation such as the Tailorable Advanced Blanket Insulation (TABI) which exhibit good surface insulation thermal properties at temperature near 2600 deg F. It was also reported by TPMB at NASA/ARC that the carbon reinforced silicon carbide ceramic matrix composite insulation (Top-Hat) was successfully tested in the 20 MW Arc-Jet

Facility where the surface temperature reaching 3000 deg F is obtained. Top-Hat TPS consists of a high temperature C/SiC cover mechanically attached to a hollowed out AETB tile packed with a lightweight alumina filler material.

To improve the repairability and minimize maintenance costs of the ceramic TPS panels, a unique mechanical attachment design has been proposed for the AMLS. It is envisioned that successful development of this technology would dramatically simplify the TPS panel installation and replacement process and greatly reduce the life cycle costs of vehicle maintenance and turnaround.

7.1.3 NASP Technology

The NASP program is currently in Phase 2D detailed design definition stage. A comprehensive technology maturation program with substantial funding is being energetically pursued to address several critical technology problems. A selected list of technologies that have potential influence on the AMLS design is shown in Table 7-3.

The advanced development efforts on the Orbital and Ascent Maneuvering System (OAMS), RCS thruster and stoichiometric gas generator are closely related to the issues of the AMLS, because both vehicles use similar propellants and have identical functional performance requirements for the on-orbit propulsion system.

In the high temperature, high performance material area, the NASP technology maturation program focuses on the characterization and development of the fabrication processes for alpha and beta titanium metal composites, advanced beryllium and refractory composites. Significant developmental data have been generated. The certification of these sophisticated materials relies on further major developments.

Both integral and non-integral tankage concepts have been investigated by the NASP program. Although the main NASP propellant tank is used for slush hydrogen storage, the design and material selection issues and thermal protection system technology requirements are similar to those for AMLS propellant tankage. Many of the technology development findings from the NASP program will be available in the early 1990's providing valuable inputs for the AMLS technology assessments. According to the current technology maturation plan, availability dates of some of these technologies are also shown in these tables.

Table 7-2. TPS Materials/Structure Technology Options.

TPS Options	Max. Temp deg F	Technology Status & Issues
<u>Nose & Leading Edges</u>		
o Carbon-Carbon Oxidation Coating Insulated Metallic Attachments High-Temp Insulation Blankets	2700	Shuttle Concept Improved Properties Permit Weight Reduction Advanced Carbon-Carbon (ACC) $\geq$ 3000°F In Development
o Carbon/Silicon Carbide (C/SiC)	3000	Being Developed for Hermes
o Silicon Carbide/Silicon Carbide (SiC/SiC)	3200	Coating May Be Required for Intermediate Temps (1600 - 2000 F)
o Ablator Avcoat	5500	Not Reusable
<u>Side & Upper Surfaces</u>		
o Blanket Insulation		
AFRSI	1500	Being Developed for Shuttle
TABI	1800	Being Developed for Shuttle
FRSI	700	Available Technology
o Bonded Ceramic Tiles L1900	1200	Shuttle Technology Low Strength, Replaced by Blankets
o Metallic Titanium Multiwall	1200	Thin Skins - Damage Prone Thicker Skin Panels Have Withstood Impact Testing
<u>Lower Surfaces</u>		
o Bonded Ceramic Tiles		
L12200	2500	Shuttle TPS Concept
FRCI	2500	More Durable Surfaces and Coating Being Developed
HTP	2500	Lighter & Stronger
AETB	2500	Waterproofing Permanent Only Below 1100 F
TUFI	2300	Lower Cost, High Impact Resistance, Repairable
o Blanket Insulation		
AFRSI	1500	AFRSI-Existing Technology
TABI	1800	Higher Temp Capability in Development
CFBI	1800	More Durable-Proposed for SSTO Composite Blanket-Lighter Weight
o Reinforced Ceramic Panels W/Fiberous or Layered Insulation (Mechanical Attachments)		
C/SiC	3000	Threaded Attachments in Gaps-Gap Fillers Needed
SiC/SiC	3200	Coating May Be Needed for 1600-2000 F
Top Hat (NASA Ames)	2700	Hard Shell Pinned to Bonded Tile
ACC Multipost	3000	Multiple Standoff Posts
Carbon-Carbon Shell	2700	NASP Concept-Buried Metallic Attachments
o Metallic		
TI Multiwall	1200	Thin Skins-Damage Prone
Superalloy Honeycomb with Fibrous Insulation	1700	
o Ablator Avcoat	5500	Not Reusable

Table 7-3a. NASP Technology.

Technology	Status: Issues	Status: Major Milestone Decisions	Status: Budget (ROM)	Availability Date(1)/ Residual Uncertainties
Rockets	OAMS Module Performance Thrust-to-Weight Life & Integration	o OAMS Module Performance Thrust-to-Weight Life & Integration o OAMS 10 Cell Module Not-Fire Tests - Nov 92 o Pump-Fed Module Hot-Fire Tests - Oct 93	$30M	Oct 92/FSED(1)
	RCS Thruster Performance, Response & Thrust-to-Weight	o RCS Thruster Hot-Fire Tests	$1M	Aug 92/FSED(1)
	OAMS/RCS Jet Interaction Effects	o Jet Interaction Tests in Hytest (M=8) Facility	$5M Incl. Hytest Facility	Feb 93/Jet Interaction Effects At High mach No. Model
	Stoichiometric Gas Generator(2) (Stoich GG) Performance	o Stoich. GG Hot-Fire Tests	$1M	Jul 92/FSED(1)
	X-30 Design Definition	o Phase 2C/2D X-30 Conceptual/ Preliminary Design	$15M	Feb 93/Phase 3 Final Design
	Phase 3 Long Lead	o Initiate Flight Component Fabrication & Development Tests	$20M	Feb 93/FSED(1)
Turbo-Machinery (Main Engine Pumps, Boost Pumps, Utility Pumps)	Bearing Life	o Small/Large Bearing Rig Tests	$4M	Dec 92
	Zero-NPSH H_2 Boost Pump Performance	o Design Fab & Test Workhorse H_2 Boost Pump	$15M	Mar 93/FSED(1)
	LH Utility Pump Performance	o Design Fab & Test	$20M	Oct 93/FSED(1)
	LO Utility Pump Performance	o Design Fab & Test Workhorse Pump	$20M	Oct 93/FSED(1)
	Main Engine H_2 Pump Performance	o Design Fab & Test Workhorse H_2 Pump	$20M	Jan 94/FSED(1)

(1) FSED - Full Scale Engineering Development
(2) Development Program Completion Date; Data Available Earlier

Table 7-3b. NASP Technology.

Technology	Status: Issues	Status: Major Milestone Decisions	Status: Budget (ROM)	Availability Date(1)/ Residual Uncertainties
Alpha TMC	Fiber/Matrix Inter-Action, Temperature Limitations, Coating Compatibility, Projected Properties Creep, Thermo-Mechanical Fatigue	o Effort to Be Evaluated Near-Term (Aero-Shell Test Articles Built From This Material)	$20-25M	Alpha Available Now Adv Alpha 1991 Alpha 2 1992
Refractory Composites	Temperature Limitations, Coating Durability, Projects Tolerance	o Effort to Be Evaluated Near-Term	$35-40M	Pre-1992
Adv Beryllium	Temperature Limitations, Cryogenic Toughness, Projected Properties	o Effort to Be Evaluated Near-Term	$1-3M	Commercial-Grade 1990 Adv Alloys 1991
Adv Heat Exchangers	Manifold Plumbing, Fabrication Tech-nology, Durability (Life), Damage Repair, Hydrogen Coolant Max Temperature Limit	o Generic Options 3&7 Aeroject Platelet	See Tech Mat Plan Budget	1991
Non-Integral Tankage-GR/EP	Volumetric Require-ment & Insulation From Hot Wall	o MDC Task B		Design Sensitive - May Need Re-evaluation
Integral Tankage	Thermal Gradients, Permeability, Fuel Liner	o Boeing Verification Cross Section Built and Tested		1990
Structural Attachments Hot Structures	Material Selection, Density, Durability, Types	o Recently Recognized As Required Effort	$2-5M	Critical Issue
Ring-Frame Attachment	Manufacturing Technology, Low Weight Design	o Task B - NASP		1990

(1) FSED - Full Scale Engineering Development
(2) Development Program Completion Date; Data Available Earlier

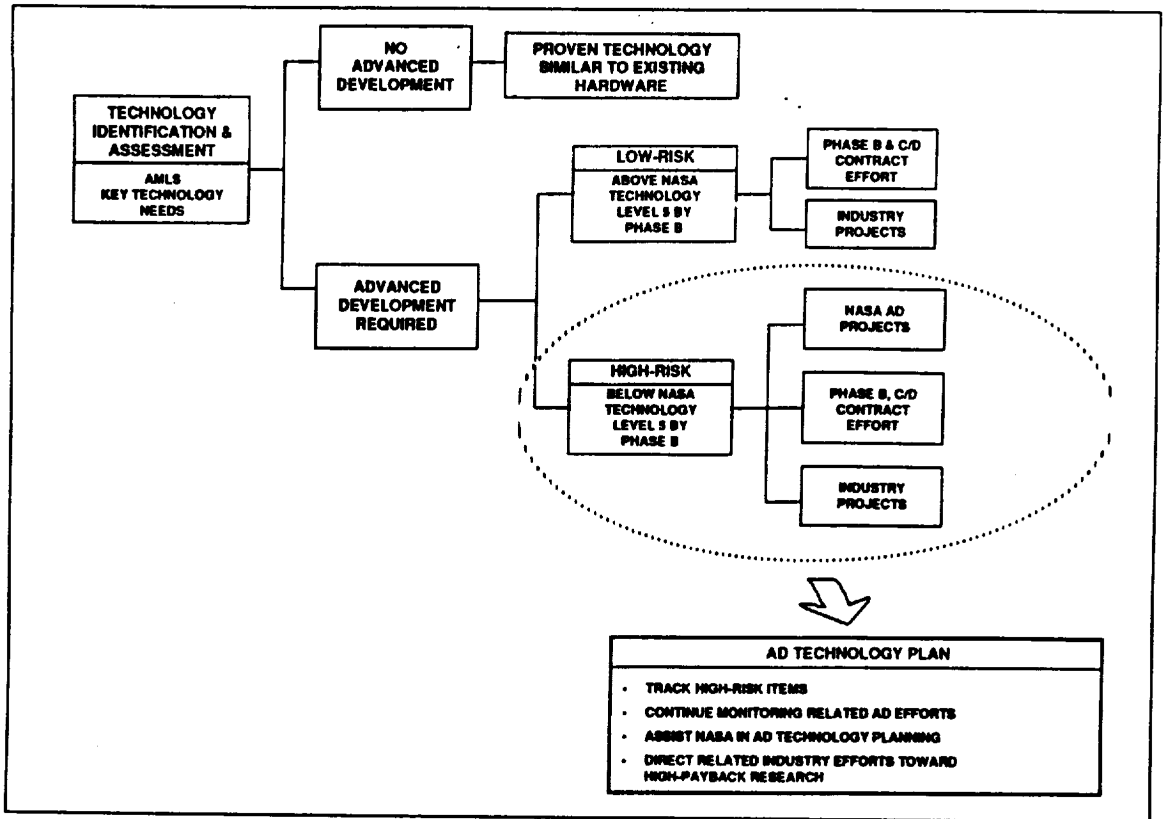


Figure 7-2. Technology Development Plan Logic.

7.2 TECHNOLOGY DEVELOPMENT PLAN

To identify candidate technologies that are critical to the AMLS design and to select the key technologies that require dedicated AMLS development effort, a set of criteria were defined and a simple logic process was followed as illustrated in Figure 7-2.

The AMLS key technology needs identified through the technology screening and assessment process can be divided into two categories:

1. the mature technologies that require no advanced development; this usually includes existing hardware that is proven and qualified

2. the enhancing technologies that require further advanced development to insure that unique AMLS mission system/operations requirements and LCC objectives can be achieved

Using the development risk and NASA technology readiness level (TRL) as the criteria, the second category of technologies can be further classified into two groups:

1. the evolving technologies which will attain a minimum level of TRL 5 by the start of the AMLS phase B program. These are considered to be low risk

2. the technologies that will be below TRL 5 at Phase B are considered to be high risk

The high risk technologies will require focused program attention to accelerate their development. Plans to upgrade their technology readiness can be implemented in the form of special NASA advanced development projects such as Phase B and C/D contracts and/or special industry research programs.

7.2.1 Technology Development Requirements

From the list of technology options presented in Section 7.1, a set of technologies was identified that reflects the key technology development needs for the AMLS. The 19 specific technologies selected, shown in Table 7-4, fall primarily into six categories:

Materials -- Candidate material that promise significant improvements in thermal properties, weight, producibility and production costs

Structures -- Advances in structure fabrication and manufacturing processes, i.e. welding and forming techniques for large aluminum-lithium primary structures; smart structures that permit incorporation of embedded sensors for detection of dynamic changes in the properties of the material at critical locations of the airframe, providing intelligence for vehicle structure life cycle/aging prediction, maintenance and logistics support

Thermal Protection Systems Innovative designs that allow the installation of TPS tiles by simple mechanical attachments, improving vehicle TPS repairability and maintenance costs

Reusable Cryogenic Tank Installation -- Major improvements in surface temperature capability, durability, and repairability

Main Propulsion System -- SSME derivative engines that have improved life, weight and margin of performance; engines that are producible at lower costs using advanced fabrication techniques and materials

Subsystems -- Technology advancements in electromechanical maintainability; advanced sensors and health monitoring systems that improve that vehicle control

Table 7-4. Key Technology Development Requirements Identified.

Technology Items	Projected TRL At Year 2000	Backup Technology Alternatives	Impacts
<u>Materials</u>			
Aluminum-Lithium	8	2219 Aluminum	Weight
Graphite-Polyimide	8	Gr/BMI Or Aluminum	Weight
Graphite-Peek	6	Gr/BMI or Gr/Epoxy	Weight, Cost
Titanium Aluminide	6	Titanium 1100	Weight
SiC/Al Metal Matrix Composites	6	Titanium	Weight
C/SiC Ceramic Composite	6	ACC	Cost, Durability
* Reusable Sofi	6	Foam Maintenance	Cost, Operations Reusability
<u>Structures</u>			
Al-Li Welding	8	2219 Aluminum	Weight
Al-Li Forming	6	Aluminum Alloys	Weight
* Smart Structures & Sensors	6**	Increased Inspection	Operations, Logistics/Maintenance LCC
<u>Thermal Protection System</u>			
* Mechanically Attached TPS Panels	6	Bonded FRCI Tiles	Durability, Operations Repairability, LCC
<u>Reusable Cryogenic Tank Insulation</u>			
* Encapsulated MLI (NASP)	6	External Insulation Rohacell	Weight, Durability, Maintenance, LCC
<u>Main Propulsion System</u>			
Low Cost SSME Derivative Engines	6	SOA Engines	Cost, Service Life Maintenance, LCC
<u>Subsystems</u>			
Electromechanical or Electrohydrostatic Actuators (NLS, SSTO)	6	'Smart' Hydraulics	Operations Cost, Reliability, Maintenance, LCC
* Health Monitoring System (NLS)	6	SOA Available Technology Increased Inspection	Operations Maintenance LCC
H2/O2 Cryogenic RCS/OMS (NASP, SSTO)	8	Hypergolic, Storable RCS/OMS	Weight, Performance, Operations, Contamination
High Power Density Fuel Cell (NASP, SSTO)	6	Shuttle Fuel Cell	Weight, Performance
* Solid State Composite Radiator	6**	Shuttle Single Phase Flow-Through Radiator	Weight, Complexity, Reliability, Operations
* Reusable Main Propulsion Engines	6	Improved SSME Derivative Engine	Weight/Performance Service Life, LCC

the complex fluid loop of a conventional heat rejection system thus providing greater systems operational reliability.

The technology readiness level (TRL) attainable for each of the key technologies by the year 2000 has been estimated based on our conservative assessment of the current ongoing technology effort and the projections of future planned research programs.

Backup technology alternatives and potential impacts were identified, if the development of some of the key technologies cannot meet the AMLS objectives and schedule requirements.

7.2.2 Advanced Development Plans

The AMLS program, according to the current master schedule, will possibly be preceded by several major related national space programs, such as NLS, NASP, PLS, and SSTO. Technology development programs for these important initiatives as well as for commercial and military aircraft will undoubtedly yield significant advancements in materials, structure fabrication, advanced avionics, and vehicle management systems. Major improvements in cryogenic H2/O2 on-orbit propulsion system can be achieved resulting in significantly reduced system mass, longer service life and greater operational flexibility.

Many of these evolving technologies listed below are critical to the AMLS and will be closely monitored in support of the next phase of AMLS design analyses and trade studies:

Low cost reusable SSME derivative engine
Advanced Avionics
Cryogenic H2/O2 RCS/OMS
Electromechanical/Electrohydrostatic actuator (EMA/EHA)
High power density fuel cells
Intelligent, autonomous vehicle management system (VMS)

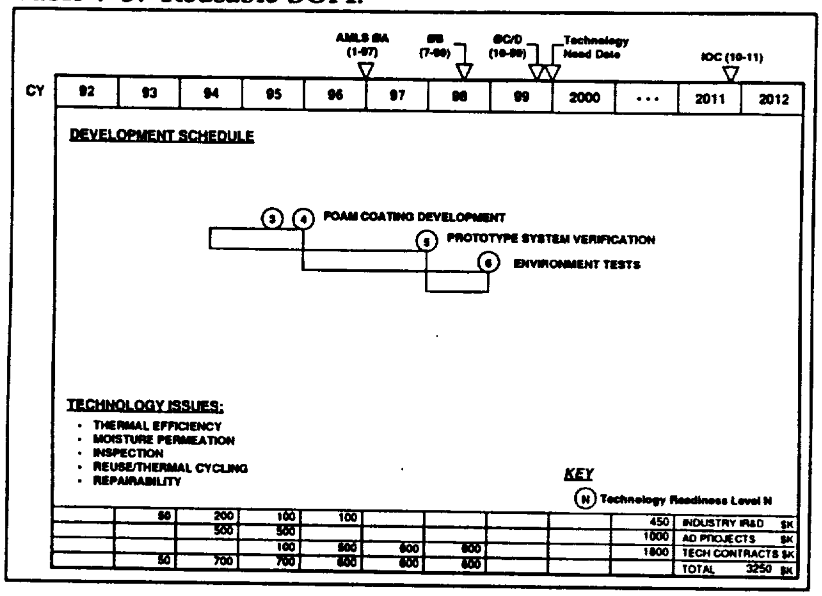
Besides these items, nine specific technologies driven primarily by the unique AMLS program schedules and system level design requirements have been identified and are recommended for advanced development. Technology development plans for these nine technologies have been generated and presented in Tables 7-5 through 7-13.

These plans show the schedules necessary to bring the respective technology to proper level of maturity to meet the AMLS program requirements. Technology issues to be addressed in the development process are identified. ROM cost estimates for the development program and funding profiles for these nine technologies are also presented. Three types of funding are identified: Industry IR&D, Advanced Development Projects, and Technology Contracts. The funding types represent progression from initial concept development and testing through verification of readiness to apply the concept to the AMLS. In this sense, readiness means the ability to manufacture cost-effectively.

Brief descriptions of the nine technology development plans are presented below:

Reusable Spray On Foam Insulation (SOFI) Reusable SOFI is a major insulation material baselined for the AMLS booster cryogenic tank design. Successful development and validation of this technology are critical for the AMLS. The technology development program, as shown in Table 7-5, will require approximately four and a half years.

Table 7-5. Reusable SOFI.



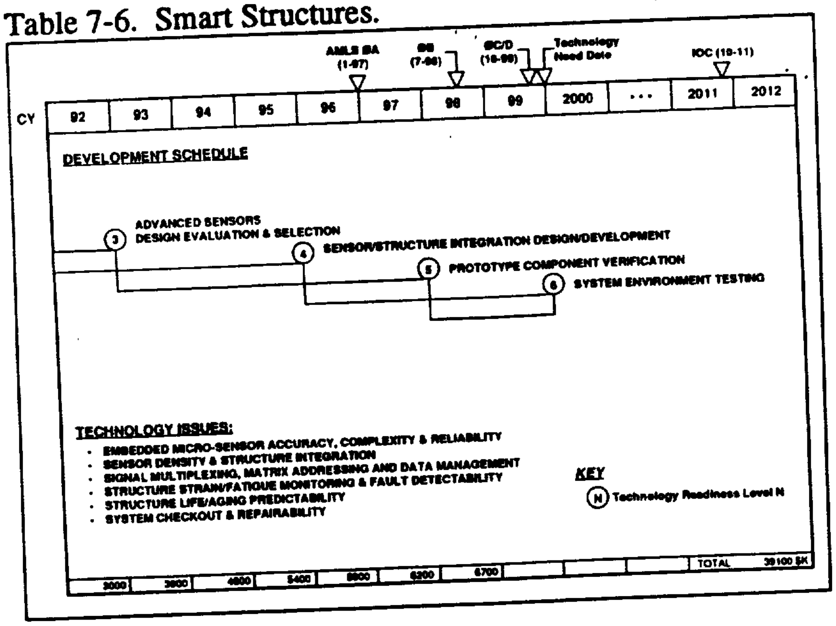
Existing non-fluorocarbon foam materials will be evaluated for strength, adherence and durability. Surface coatings will be evaluated, including integral, reinforced and bonded skins, and suitable concepts will be selected for development. Prototype foam systems will be tested under severe environmental conditions to assure maturity of the selected approach.

Smart Structures Smart structure technology relies on the development of highly accurate micro-sensors that can be produced in quantity at extremely low costs. Advanced sensors that are in early concept validation stages, include fiber optic, electromagnetic/dielectric, and acoustic sensors. These tiny sensing devices, either materially imbedded or bonded to structures at critical locations as point or array sensors, can monitor the changes of the structure strain field and dynamic vibration spectra that can be interpreted by inversion to identify shifts in structure integrity and strength.

High speed, high capacity data processing computing hardware and software must be developed. Networking techniques, such as frequency, wavelength or time division multiplexing and matrix addressing, which enable simultaneous operation of many sensors with a minimum of opto-electric and microprocessor hardware and structural invasiveness are essential part of the technology development.

The technology plan Table 7-6, shows that this important technology can be brought to a NASA technology level 6 of maturity by the year 2000 by implementing an

Table 7-6. Smart Structures.



energetic research program supported by the government, the aerospace industry, and academic research communities.

A sketch showing a typical fiber optic sensor embedded at critical locations in a structure and associated electronic signal processing equipment is presented in Figure 7-3. A brief description of the principle of operation of the fiber optic sensor is also included.

Mechanically Attached TPS The technique of using mechanical means to install the TPS on the structure instead of the conventional bonding process is still in very early stages of development. Many complex technology issues, e.g., gap seal design and subsurface flow effects have not been addressed.

A significant (8 year) technology program was envisioned as shown in Table 7-7 is needed to validate this approach. The technology program will include design of an integrated TPS panel/fastening system. Materials for the high-temperature fasteners will be evaluated. Prototype panels will be fabricated and tested under realistic thermal conditions to verify the concept. Prototype TPS system panels will be built to incorporate gap seals and flow barriers. Wind Tunnel and flight tests will be conducted to validate the design. Environmental testing will be conducted to assure successful service application of the mechanically attached TPS concept.

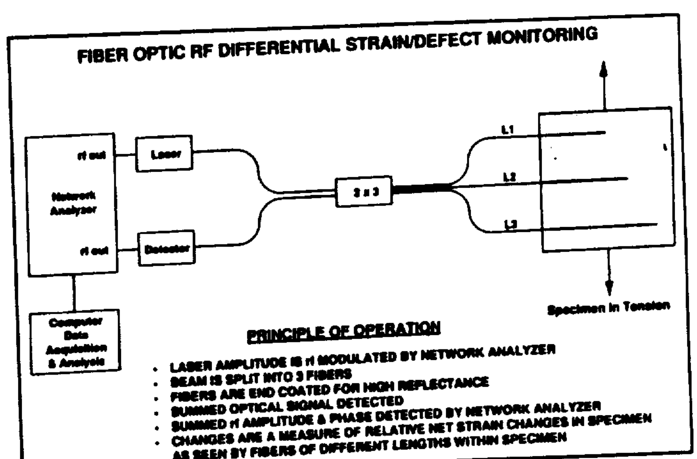
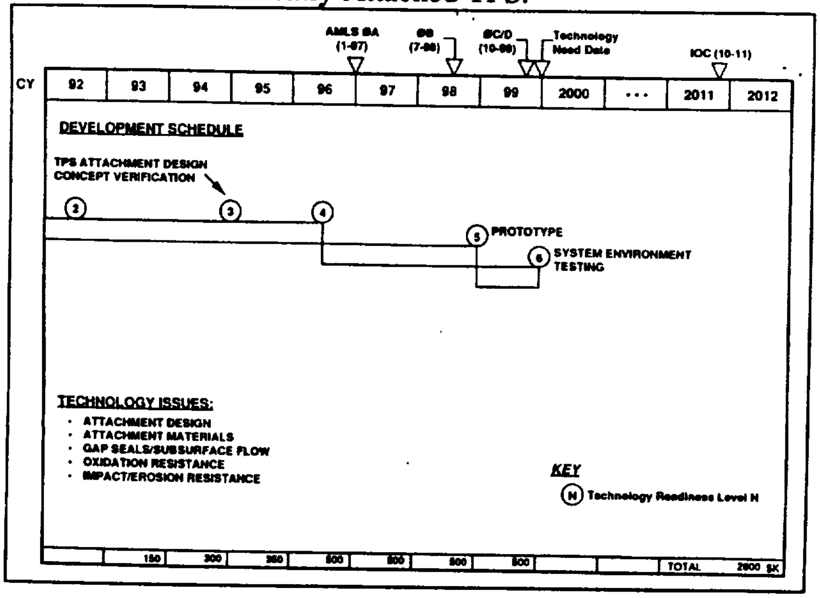


Figure 7-3. Smart Sensors for Life and Maintenance Monitoring.

Encapsulated MLI Significant progress on this unique and innovative cryogenic tank insulation system was made during the early NASP technology maturation program. Prototype panels demonstrated outstanding thermal performance

Table 7-7. Mechanically Attached TPS.



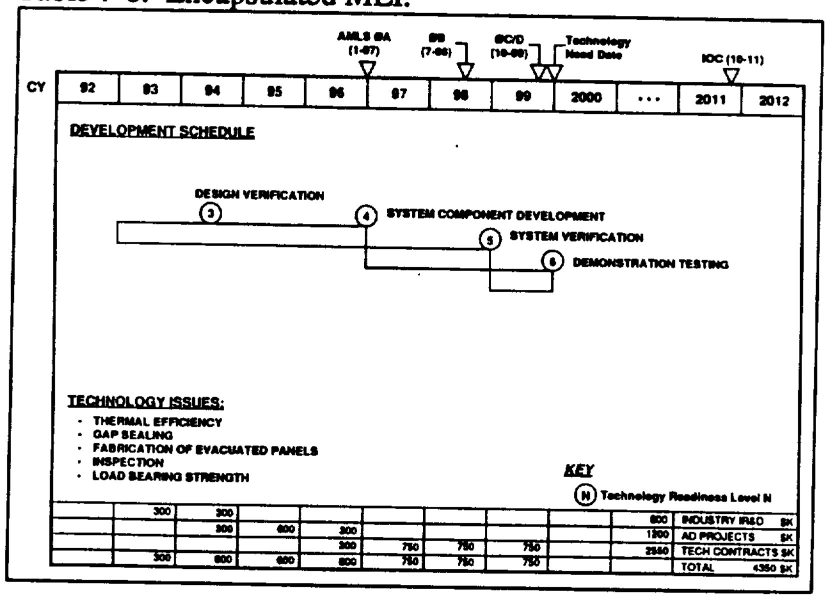
characteristics, especially at extremely high (1500 degree F) temperatures. Additional development work, as shown in the Table 7-8, is required to validate the MLI concept for long-term repeated use.

New lighter-weight materials will be selected for the aluminum tank application. Concepts for attaching the insulating panels and for sealing their joints will be developed. System components that incorporate these details as well as insulation of major internal frames and stiffness will be developed. The system will be verified in a sub-scale cryogenic tank test. Demonstration testing will include thermal cycling to cryogenic temperatures and environmental effects due to maximum temperatures, acoustic vibration and structural flexure.

A schematic showing the MLI installed inside the cryogenic tank structure is presented in Figure 7-4. The internal structure of the metal-cover-encapsulated MLI is illustrated in the cross sectional diagram.

Health Monitoring System To improve the effectiveness and safety of the vehicle flight control and autonomous operations, AMLS will require advancements in avionics system architecture design and in sophistication of data processing, health monitoring, failure detection, diagnostic and prognostic capability and reconfiguration management.

Table 7-8. Encapsulated MLI.



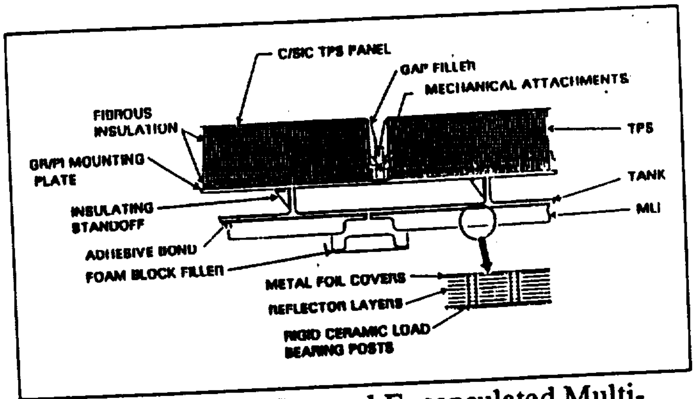


Figure 7-4. Internal Encapsulated Multi-Layer Insulation (MLI) Concept.

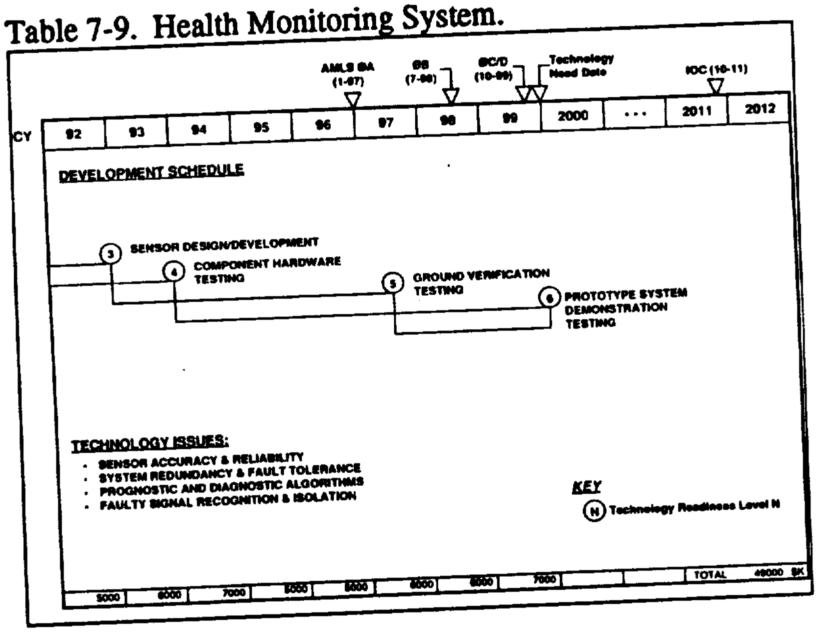
Recent advancements in sensor technologies have significantly enhanced the capability and effectiveness of health monitoring system. On the basis of the status information of the current ongoing related technology programs, it is envisioned that a health monitoring system program for the AMLS as shown in Table 7-9 is warranted.

As illustrated in Figure 7-5, HMS is a versatile concept that can be applied to all phases of the AMLS vehicle life. It can be used in every aspect of the vehicle fabrication, test, and verification process. It plays the most significant role in vehicle operations. Safety monitoring will increase system reliability. Maintenance monitoring will reduce logistics costs.

Solid State Composite Radiator The use of high conductance materials, e.g., graphite fiber composite, for construction of a space radiator is an emerging technology. It eliminates the complexity of the fluid loops of the conventional state-of-the-art radiators and increases significantly the reliability of the system. A comparison of the system characteristics of the various types of radiator concepts is shown in Figure 7-6.

Early laboratory experiments, conducted by Research Opportunities Inc., for the U.S Navy, using high conductivity carbon fibers embedded in a composite panel have demonstrated the viability and effectiveness of the radiator concept. Successful development of this technology is deemed important for the AMLS. The proposed technology development program is shown in Table 7-10.

Table 7-9. Health Monitoring System.



Reusable Main Propulsion Engines The technology plans presented in Tables 7-11 through 7-13 reflects the three critical development activities related specifically to the SSME derivative engines. These programs will produce generic technologies deemed essential for the AMLS main propulsion

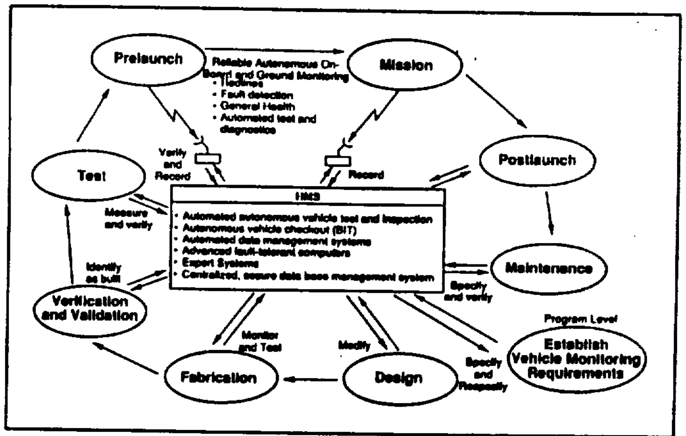


Figure 7-5. HMS Applied in All Phases of Vehicle Cycle Life.

engine design and development. The technology issues that will be addressed specifically in these plans include:

AMLS - SSME with reduced weight
SSME derivative for increased margin
SSME with producibility improvements

These programs are aimed at obtaining significant improvements in SSME reliability and life/performance margins. Substantial reduction in engine production costs is also being sought through the use of advanced materials and simplification of fabrication techniques and testing processes.

The National Launch System (NLS) program, managed jointly by NASA and U.S. Air Force, will have a major main propulsion engine technology development effort. It has been indicated that a national consortium of rocket propulsion companies will be assembled to perform this research and development project. Major technical emphasis of the project, known as the Space Transportation Main Engine (STME) program, is being placed on the development of an advanced high thrust, low chamber pressure, low cost engine that has inherent design characteristics of high reliability and safety. All these performance features are consistent with the AMLS main engine design requirements. Our technology assessments show that reusability appears to be a requirement especially important for the AMLS engine. Nevertheless, generic technologies derived from the STME program can serve as a basis upon which a cost effective reusable AMLS main engine technology development program can be further evolved.

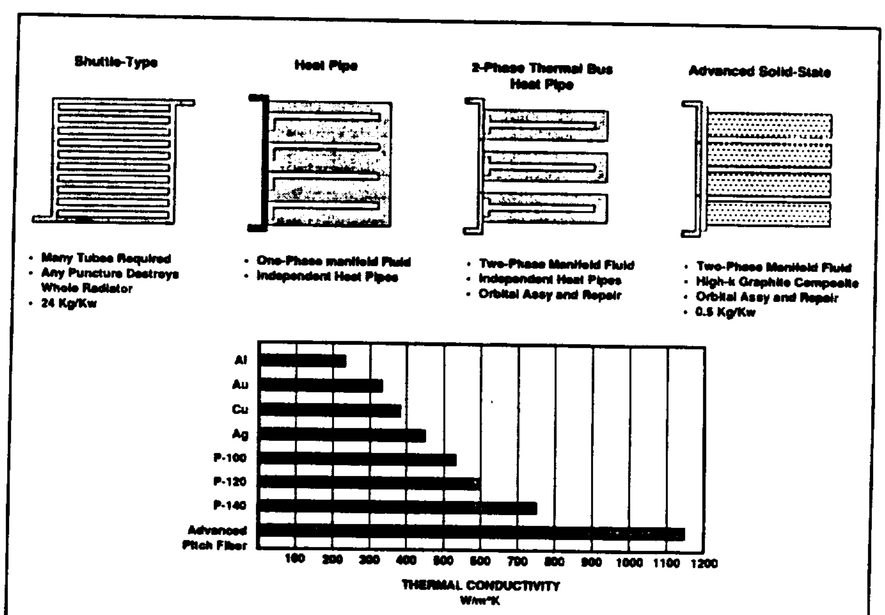


Figure 7-6. Solid State Composite Radiator.

Table 7-10. Solid State Composite Radiator.

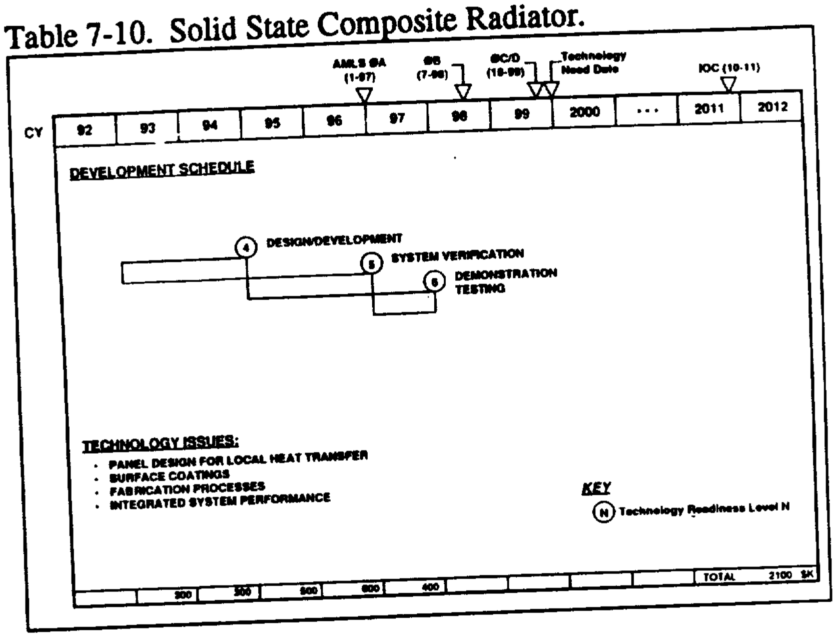


Table 7-11. SSME with Reduced Weight.

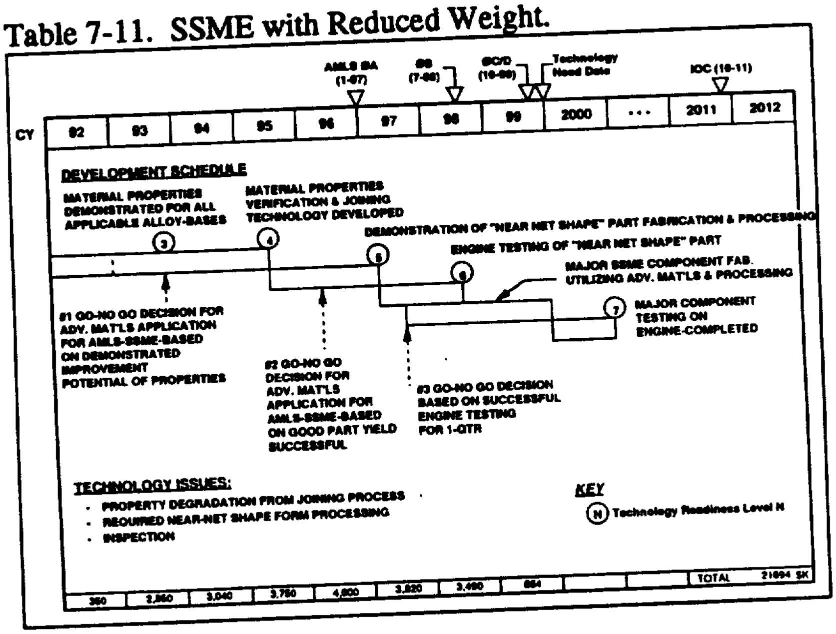


Table 7-12. SSME Derivative for Increased Margin.

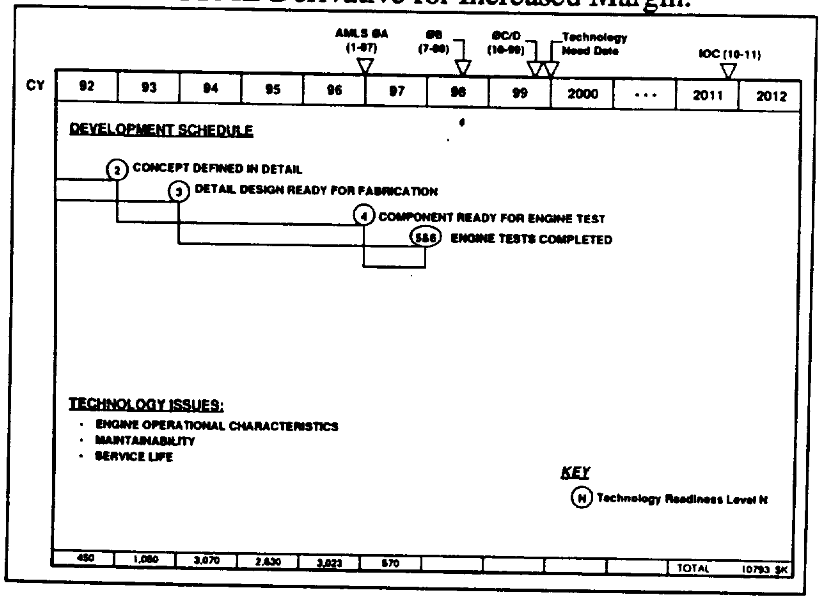
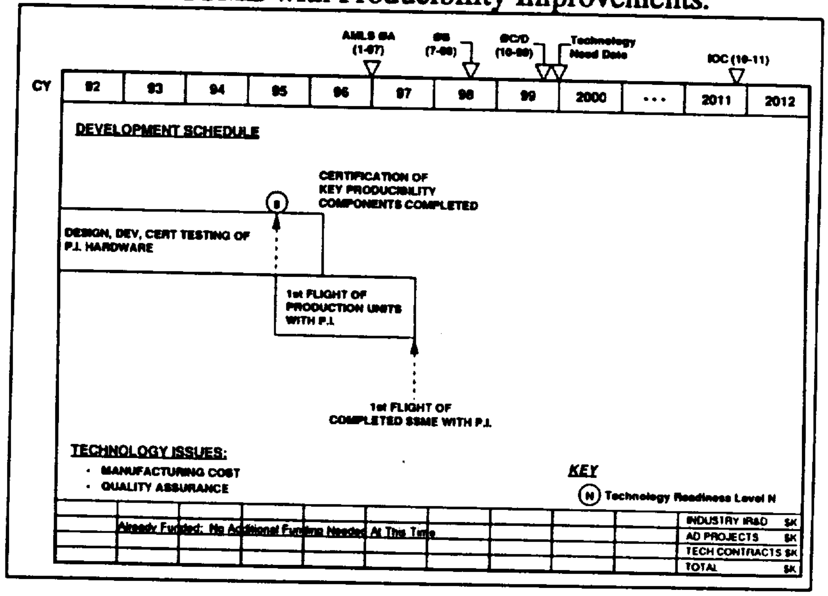


Table 7-13. SSME with Producibility Improvements.



BIBLIOGRAPHY

1-1. Advanced Manned Launch System - Study Ground Rules (Task 3). NAS1-18975, Space Systems Division, Rockwell International Corporation, SSD91D0269 (May 10, 1991).

1-2. Advanced Manned Launch System.- Hardware/Software Design Description (Task 3). NAS1-18975, Space Systems Division, Rockwell International Corporation, STS91D0675 (September 27, 1991).

1-3. Advanced Manned Launch SystemStudy- Acquisition Phase Definition. (Task 3). Contract NAS1-18975 , Space Systems Division, Rockwell International Corporation, SSD91D0676 (September 27, 1991).

1-4. Advanced Manned Launch System.-Operations & Support Analysis (Task 3). NAS1-18975, Space Systems Division, Rockwell International Corporation, SSD91D0677` (September 27,1991).

1-5. Advanced Manned Launch System - Life Cycle Cost Analysis (Task 3). NAS1-18975, Space Systems Division, Rockwell International Corporation, SSD91D0678 (December 9, 1991).

1-6. Advanced Manned Launch System - Technology Development Plan (Task 3). NAS1-18975, Space Systems Division, Rockwell International Corporation, SSD91D0679 (September 27,1991).

3-1 Integrated Hydrogen/Oxygen Technology (IHOT). Space Systems Division, Rockwell International Corporation, NASA Contractor Report CR-185289 (Sept. 1990).

3-2 Personnel Launch System (PLS) - Advanced Manned Launch System Study (AMLS) Final Oral ReviewBriefing. Space Systems Division, Rockwell International Corporation, SSD 900063A, (July 17-18, 1990).

4-1. Advanced Manned Launch System - Life Cycle Cost Analysis (Task 3). NAS1-18975, Space Systems Division, Rockwell International Corporation, SSD91D0678 (December 9, 1991).

4-2. Advanced Manned Launch System - Technology Development Plan (Task 3). NAS1-18975, Space Systems Division, Rockwell International Corporation, SSD91D0679 (September 27,1991).

4-3. Total Quality Management (TQM) - Key Features of the DoD Implementation of TQM, Department of Defense DoD 5000.51-G-Draft (August 1, 1991).

4-4. R&M 2000 Process - Acquisition Management, United States Air Force, AFP 800-7, PAMPHLET (January 1, 1989)

4-5. Advanced Manned Launch System.-Operations & Support Analysis (Task 3). NAS1-18975, Space Systems Division, Rockwell International Corporation, SSD91D0677 (September 27,1991).

4-6. DataMyte Handbook - A Practical Guide to Computerized Data Collection for Statistical Process Control, 3rd Edition, DataMyte Corporation, Minnetonka, MN- HANDBOOK (June 1987)

4-7. Advanced Manned Launch System - Study Ground Rules (Task 3). NAS1-18975, Space Systems Division, Rockwell International Corporation, SSD91D0269 (May 10, 1991).

4-8. Advanced Manned Launch System. - Subsystems Design & Analysis (Task 3). NASA18975, Space Systems Division, Rockwell International Corporation, SSD91D0271-1,-2,-3 (June 28, 1991).

4-9. Advanced Manned Launch System.- Hardware/Software Design Description (Task 3). NAS1-18975, Space Systems Division, Rockwell International Corporation, STS91D0675 (September 27, 1991).

6-1. Advanced Manned Launch System Life Cycle Cost Analysis (Task 1). Contract NAS1-18975, Space Systems Division, Rockwell International Corporation, SSD90D0095 (September 10, 1990).

6-2. Advanced Manned Launch System - Technology-DevelopmentPlan (Task3). NAS1-18975, Space Systems Division, Rockwell International Corporation, SD91D0679-5 (September 7, 1991).

6-3. Advanced Manned Launch SystemStudy- Acquisition Phase Definition. (Task 3). Contract NAS1-18975 , Space Systems Division, Rockwell International Corporation, SSD91D0676 (September 27, 1991).

6-4. Advanced Manned Launch System - Study Operations and Support Analysis (Task 3). Contract NAS1-18975, Space Systems Division, Rockwell International Corporation, SSD91D0677 (September 27, 1991).

7-1. NASA Space Systems Technology Model. National Aeronautics and Space Administration, Washington, DC., (1984).

7-2. Space Transportation Architecture Study-Technology Assessment and Development Plan. Space Systems Division, Rockwell International Corporation, STS 87-0522.

7-3. Advanced Launch Systems - Volume 1. Technology Development and Demonstration Plan. Space Systems Division, Rockwell International Corporation STS-88-0691-1.

7-4 Air Force Logistics Research and Development Program Document Air Force Office for Logistics Technologies Applications (AFOLTA), Wright-Patterson AFB (July 1989).

7-5. Air Force Technology Transfusion Opportunities Program Document.. Air Force Office for Logistics Technologies Applications (AFOLTA), Wright-Patterson AFB (July 1989).

7-6. Advanced Military Spaceflight Capability (AMSC) -Technology Identification Study. Space Systems Division, Rockwell International, AFWAL-TR-83-3055 (June 1983).

7-7. Space Research and Technology Program and Specific Objectives National Aeronautics and Space Administration, Washington, D.C., (1988).

7-8. Technology for Space Station Evolution - A Workshop. [Copies of Presentation Vu-Graphs], sponsored by NASA Office of Aeronautics and Space Technology (Code R), now Office of Exploration Technology (OET), at Dallas, Texas, (January, 1990).

7-9. Guidelines for Man Rating Space Systems. Advanced Programs Office, Systems Definition Branch, Systems Analysis Section, NASA Lyndon B. Johnson Space Center, Report JSC-23211 (September, 1988).

7-10. Design Goals and Technology Requirements For Future Launch Systems. - Executive Summary, Eagle Engineering/LEMSCO, for Advanced Programs Office of the NASA Lyndon B. Johnson Space Center, Report No. 88-186. (April 18, 1988).

7-11. Technology Influence on the Space Shuttle Development. NASA Lyndon B. Johnson Space Center, Houston, TX, (June 8, 1986).

7-12. Space Shuttle Directions. Advanced Programs Office, NASA Lyndon B. Johnson Space Center, Report JSC-20939 (June, 1986).

7-13. Space Transportation Avionics Technology Symposium-1989. Nasa Office of Space Flight, Advanced Program Development, (November 7-9, 1989).

7-14 National Aerospace Plane (NASP) Airframe Technology Option 5. Sealing Concepts. The Boeing Co.,. Report D180-31720-1 (July 1989).

7-15. Progress Toward the Development of Real Time Monitoring Capabilities in a Rocket Engine - Health Monitoring System Laboratory Testbed. Rocketdyne Division, Rockwell International , AIAA/ASME/SAE/ASEE 25th Joint Propulsion Conference, Monterey, CA, AIAA-89-2759, (July 10-12, 1989).

7-16. Report of the National Critical Technology Panel. Office of Science and Technology Policy, Arlington VA, (March 22, 1991).

7-17. America at the Threshold. Syntheis Group, T. P. Stafford, Arlington VA, (May 6, 1991).

OTHER SOURCES

- Data Item Descriptions (DID's)
- Conference Minutes, 2/18/81
- DI-MISC-80074, Manufacturing Plan, 12/9/85
- Specifications
- DoD 4245.7M, Transition From Development to Production, 9/1/85
- DOD Directive 4245.7 M, Transition From Development to Production, 1/19/84
- DoD-STD-100 C, Engineering Drawing Practices [Tailored], 12/22/78,[Notice 4] [5/4/83]
- DoD-STD-2167, Defense System Software Development, 6/4/85 [Tailoring deferred to Phases B and/or C/D]
- A, Quality Program Requirements [Tailoring deferred to Phases B and/or C/D], 3/8/85, Amendment 2
- MIL-STD-470 A, Maintainability Programs for Systems & Equipment [Tailored], 1/3/83
- MIL-STD-483 A, Configuration Management Practices for Systems Equipment, Munitions, & Computer Programs [Tailored], 6/4/85
- MIL-STD-490 A, Specification Practices [Tailored], 6/4/85
- MIL-STD-499 A, Engineering Management [Tailored], 5/1/74
- MIL-STD-781 D, Reliability Testing for Engineering Development, Qualification, and Production [Tailored], 10/17/86
- MIL-STD-785 B, Reliability Program for Systems and Equipment Development and Production [Tailored], 9/15/80
- MIL-STD-1388-1 A, Logistics Support Analysis [Tailored], 4/11/83

- MIL-STD-1521 B, Technical Reviews & Audits for Systems, Equipments, & Computer Software, 6/4/85

- MIL-STD-1528 A, Manufacturing Management Program [Tailored], 9/9/86

- MIL-STD-1540 B, Test Requirements for Space Vehicles [Tailoring deferred to•Phases B and/or C/D], 10/10/82

- MIL-STD-1543 A, Reliability Program Requirements for Space & Launch Vehicles [Tailored], 6/25/82

- MIL-STD-1546 A, Parts, Materials, and Processes Control Program for Space & Launch Vehicles [Tailoring deferred to Phases B and/or C/D], 3/1/88

- MIL-STD-1547 A, Parts, Materials, and Processes for Space & Launch Vehicles, Technical Requirements for [Tailoring deferred to Phases B and/or C/D], 10/31/80, [NOTICE 1], 4/10/81

- MIL-STD-1629 A, Procedures of Performing a Failure Mode, Effects and Critically Analysis [Tailored], 11/24/80

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To assure national leadership in space operations and exploration in the future, NASA must be able to provide cost effective and operationally efficient space transportation. Several NASA studies and the joint NASA//DoD Space Transportation Architecture Studies (STAS) have shown the need for a multi-vehicle space transportation system with designs driven by enhanced operations and low costs. The NASA is currently studying an advaced manned launch system (AMLS) approach to transport crew and cargo to the Space Station Freedom. Several single and multiple stage systems from air-breathing to all-rocket concepts are being examined in a series of studies potential replacements for the Space Shuttle launch system in the 2000-2010 time frame. Rockwell International Corporation, under contract to the NASA Langley Research Center, has analyzed a two-stage all-rocket concept to determine whether this class of vehicles is appropriate for the AMLS function. This report discusses the results of the pre-phase A study.

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